
Procedure



Phased Array Ultrasonic Testing Procedure

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REVISION INDEX

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1.0 PURPOSE

- 1.1 The purpose of this procedure is to provide the specific requirements, methods, and techniques to be used when performing, evaluating, and documenting contact Phased Array Ultrasonic (PAUT) Examinations of ASME Section I and VIII Pressure Vessel Welds and B31.1 & B31.3 Piping Welds.

2.0 SCOPE

- 2.1 This procedure is applicable to ultrasonic weld examinations in rolled, drawn, forged, or extruded product forms in pressure vessel butt and nozzle welds, as well as piping butt and attachment welds.
- 2.2 Pressure Vessel Welds - This procedure is intended for the use of MUT examinations on pressure vessel butt and nozzle welds with thicknesses ≥ 0.250 " for the detection of fabrication flaws.
- 2.3 Piping Welds - This procedure is intended for the use of MUT examination of piping butt welds and full penetration attachment welds with thicknesses ≥ 0.250 " for the detection of fabrication flaws.
- 2.4 This procedure applies to single vee, double vee, J-bevel joint, single bevel, double bevel configurations of butt weld, as well as sit-in or set-on nozzle welds.
- 2.5 This procedure is to be used only when welds being examined are in the surface temperature range of 40°F to 200°F.
- 2.6 This procedure covers the general method for contact scanning from the O.D. surfaces with equipment and techniques utilizing Phased Array transducers and wedges capable of generating shear waves between 0° and 75° as detailed in approved scan plans.
- 2.7 Procedure Qualification - When procedure qualification is specified, by an ASME referencing Code Section, a change of an essential variable from the specified value, or range of values listed in Tables T-421 and V-421 of Article 4 in Section V, shall require requalification of this written procedure by demonstration. A change of a nonessential variable from the specified value, or range of values listed in Tables T-421 and V-421 does not require requalification of this written procedure. All changes of essential or nonessential variables specified within this written procedure shall require a revision of, or an addendum to, this written procedure.

Table T-421
Requirements of an Ultrasonic Examination Procedure

Requirement	Essential Variable	Nonessential Variable
Weld configurations to be examined, including thickness dimensions and base material product form (pipe, plate, etc.)	X	...
The surfaces from which the examination shall be performed	X	...
Technique(s) (straight beam, angle beam, contact, and/or immersion)	X	...
Angle(s) and mode(s) of wave propagation in the material	X	...
Search unit type(s), frequency(ies), and element size(s)/shape(s)	X	...
Special search units, wedges, shoes, or saddles, when used	X	...
Ultrasonic instrument(s)	X	...
Calibration [calibration block(s) and technique(s)]	X	...
Directions and extent of scanning	X	...
Scanning (manual vs. automatic)	X	...
Method for discriminating geometric from flaw indications	X	...
Method for sizing indications	X	...
Computer enhanced data acquisition, when used	X	...
Scan overlap (decrease only)	X	...
Personnel performance requirements, when required	X	...
Personnel qualification requirements	...	X
Surface condition (examination surface, calibration block)	...	X
Couplant: brand name or type	...	X
Post-examination cleaning technique	...	X
Automatic alarm and/or recording equipment, when applicable	...	X
Records, including minimum calibration data to be recorded (e.g., instrument settings)	...	X

**Table V-421
Requirements of Phased Array Linear Scanning Examination Procedures**

Requirements (as Applicable)	Workmanship		Fracture Mechanics	
	Essential	Nonessential	Essential	Nonessential
Weld configurations examined, including joint design, thickness, and base material product form	X	...	X	...
Surfaces from which examination is performed	X	...	X	...
Surface condition (examination surface, calibration block)	X	...	X	...
Weld axis reference system and marking	X	...	X	...
Personnel qualification requirements	X	...	X	...
Personnel performance demonstration (if required)	X	...	X	...
Primary reference reflector and level	X	...	X	...
Calibration [calibration block(s) and technique(s)]	X	...	X	...
Standardization method and reflectors (wedge delay, sensitivity, TCG)	X	...	X	...
Computerized data acquisition	X	...	X	...
Wedge cut/natural refracted angle	X	...	X	...
Wedge contouring and/or stabilizing features	X	...	X	...
Wedge height	X	...	X	...
Wedge roof angle, if applicable	X	...	X	...
Wedge type (solid wedge, water column, etc.)	X	...	X	...
Wedge material	X	...	X	...
Scanner type and fixturing	X	...	X	...
Search unit mechanical fixturing device (manufacturer and model), adhering and guiding mechanism	X	...	X	...
Search unit separation, if applicable	X	...	X	...
Couplant brand name or type	...	X	...	X
Instrument manufacturer and model, including all related operating modules	X	...	X	...
Instrument software and revision [Note (1)]	X	...	X	...
Use of separate data analysis software and revision [Note (1)]	X	...	X	...
Search unit type (linear, dual linear, dual matrix, tandem, etc.)	X	...	X	...
Search unit detail (frequency, element size, number pitch, gap dimensions, element shape)	X	...	X	...
Technique(s) (straight beam, angle beam, contact, and/or immersion)	X	...	X	...
Angle(s) and mode(s) of wave propagation in the material	X	...	X	...
Direction and extent of scanning	X	...	X	...
Scanning technique (line vs. raster)	X	...	X	...
Scanning technique (automated vs. semiautomated)	X	...	X	...
Scanning (manual vs. encoded)	X	...	X	...
Scan increment (decrease in overlap)	X	...	X	...
Use of scan gain over primary reference level	X	...	X	...
Virtual aperture size (i.e., number of elements, effective height, and element width)	X	...	X	...
Focus length and plane (identify plane projection, depth, or sound path, etc.)	X	...	X	...
For E-scan				
Range of element numbers used (i.e., 1-126, 10-50, etc.)	X	...	X	...
Element incremental change (i.e., 1, 2, etc.)	X	...	X	...
Rastering angle	X	...	X	...
Aperture start and stop numbers	X	...	X	...
For S-scan:				
Aperture element numbers (first and last)	X	...	X	...
Decrease in angular range used (i.e., 40 deg to 50 deg, 50 deg to 70 deg, etc.)	X	...	X	...
Maximum angle incremental change (i.e., 1/2 deg, 1 deg, etc.)	X	...	X	...
For compound E-scan and S-scan: all E-scan and S-scan variables apply	X	...	X	...
Digitizing frequency	X	...	X	...
Net digitizing frequency (considers digitization frequency together with points quantity or other data compression)	X	...	X	...
Instrument dynamic range setting	X	...	X	...
Pulser voltage	X	...	X	...
Pulse type and width	X	...	X	...
Filters and smoothing	X	...	X	...

**Table V-421
Requirements of Phased Array Linear Scanning Examination Procedures (Cont'd)**

Requirements (as Applicable)	Workmanship		Fracture Mechanics	
	Essential	Nonessential	Essential	Nonessential
Pulse repetition frequency	X	...	X	...
Maximum range setting	X	...	X	...
Use of digital gain	X	...	X	...
Method for discriminating geometric from flaw indications	X	...	X	...
Flaw characterization methodology	X	...	NA	NA
Method for measuring flaw length	X	...	X	...
Method for measuring flaw height	NA	NA	X	...
Method for determining indication location relative to surface	NA	NA	X	...
Method for determining indication relative to other indications	NA	NA	X	...
Records, including minimum calibration data to be recorded (e.g., instrument settings)	...	X	...	X
Post-exam cleaning	...	X	...	X

GENERAL NOTE: NA = not applicable.

NOTE:

(1) Use of later software revisions shall be evaluated by the Level III for their impact on the functions as used. A limited extension of qualification may be determined to prove software functions. For example, addition of a software feature more capable than that already qualified may be qualified by reanalysis of existing data. If a revision is implemented, personnel shall receive training in use of the revised software.

3.0 DEFINITIONS

3.1 Ultrasonic examination definitions and terminology shall be in accordance with Mandatory Appendix I, paragraph I-121 and I-121.2 UT, in Article 1 of the ASME Section V Code.

4.0 REFERENCE DOCUMENTS

4.1 The following National Codes, Standards, and Specifications, were referenced in the preparation of this document:

- 4.1.1 ASME BPVC Section I, Rules for Construction of Power Boilers, 2025 Edition
- 4.1.2 ASME BPVC Section V, Nondestructive Examination, 2025 Edition
- 4.1.3 ASME BPVC Section VIII (Div. 1 & 2), Rules for Construction of Pressure Vessels, 2025 Edition
- 4.1.4 ASME B31.1, Power Piping, 2024 Edition
- 4.1.5 ASME B31.3, Process Piping, 2024 Edition
- 4.1.7 IPS-WP-01, IPS' Written Practice for the Qualification and Certification of NDE Personnel
- 4.1.8 ASNT, RP No. SNT-TC-1A

5.0 PERSONNEL REQUIREMENTS

5.1 Personnel who perform, analyze, interpret data, or report results shall be qualified and certified in accordance with the IPS Written Practice IPS-WP-01, as a PAUT Level II or III.

5.2 Personnel shall have training using the examination and evaluation

equipment and software.

6.0 EQUIPMENT REQUIREMENTS

6.1 Instrument Requirements

- 6.1.1 The ultrasonic instrument approved for use with this procedure is:
 - 6.1.1.1 Olympus MX2, MXU 4.8; X3 MXU 5.9, or later
 - 6.1.1.2 Other instruments may be used with responsible level III approval
- 6.1.2 The encoding capabilities of the instrument shall not be altered or limited by the number of scans generated or probes used per Section 7.0 of this procedure.
- 6.1.3 The dampening control may be used if it is proven during calibration/qualification to not reduce the sensitivity of the examination. The reject control shall remain "off" for all examinations.
- 6.1.4 Any Video Filtering (other than receiver filters) or Smoothing settings shall remain in the "off" position during all examinations.
- 6.1.5 The frequency range of the unit shall be such that it can accommodate the search units to be used per paragraph 6.2.
- 6.1.6 Instrument Linearity Checks - The requirements of paragraphs 6.1.6.1 and 6.1.6.2 shall be met at intervals not to exceed three months for analog type instruments and one year for digital type instruments, or prior to first use thereafter.
 - 6.1.6.1 Screen Height Linearity. The ultrasonic instrument's screen height linearity shall be evaluated and meet the requirements of Mandatory Appendix I in Article 4 of ASME Section V.
 - 6.1.6.2 Amplitude Control Linearity. The ultrasonic instrument's amplitude control linearity shall be evaluated and meet the requirements of Mandatory Appendix III in Article 4 of ASME Section V.

6.2 Search Units

- 6.2.1 Phased Array probes shall be of the linear array type. The nominal frequency of the probe shall be from 1 to 10 MHz unless variables, such as production material grain structure, require the use of other frequencies to assure adequate penetration or better sensitivity. Search units with contoured wedges may be used to aid ultrasonic coupling.
- 6.2.2 The same search unit (transducer and wedge) and nominal frequency used during calibration shall be the same used during the examination and the qualification process.
- 6.2.3 Transducers with 10 to 16 elements may be used when the nominal part thickness is less than 1/2" thick. For greater thicknesses, transducers shall contain 16 or more elements.

- 6.2.4 Element pitch dimensions shall be small enough not to generate unwanted grating lobes during the examination. The element pitch dimension should be less than one-half of the wavelength for given probe being utilized in the examination. The pitch size used in qualification shall be the same pitch size used during all subsequent examinations.
- 6.2.5 Contact Wedges – When required below, examinations performed on a curved component shall be performed using a contoured wedge, to ensure sufficient ultrasonic coupling is achieved and to limit any potential rocking of the search unit as it is moved along the circumference of the component.
- 6.2.6 Wedges shall be contoured if the component diameter to be examined is equal to or less than D using the calculation below:

$$D \leq \frac{A^2}{0.113 \text{ in. (2.87 mm)}}$$

Where:

A = length of search unit footprint during circumferential scanning or the width when scanning in the axial direction, in.

D = the component diameter at the examination surface (O.D.), in.

The footprint is defined as the physical dimension of the search unit in the curved direction of the component.

- 6.2.7 When required per above, the wedge contour dimension shall be selected from Table 1 below and shall be determined using the same component dimension from which the examination is being performed (O.D.).

Table 1	
Maximum contour for examinations performed from O.D.	
Actual Component Outside Diameter, in (mm)	Allowable Increase in Contour Diameter Over Component O.D, in. (mm)
<4 (<100)	-0 to +1 (+25)
≥4 to 10 (≥100 to <250)	-0 to +2 (+50)
≥10 to <18 (≥250 to <455)	-0 to +4 (+100)
≥18 to <23 (≥455 to <580)	-0 to +6 (+150)
≥23 (>580)	-0 to +10 (+250)

- 6.2.8 Wedge Angle Selection: Wedges shall be used within the recommended ranges detailed by the manufacturer. Utilization outside of these recommended ranges may cause unwanted grating lobe interference.

- 6.2.9 Search Unit Combinations: Allowed PAUT search unit combinations are listed in the table below. Other search unit combinations may be

used provided comparable pitch dimensions are present for the comparable number of elements in the probe housing. Once the scan plan is designed and qualified, the same search unit combination used in qualification shall be used for examination.

6.2.10 Phased array transducer element pitch and gap are essential variables. Other transducer factors such as frequency are equally important and are specified essential variables. Control of these variables is considered met when the make and model of transducer is specified. Substitution of a transducer from a different manufacturer or model changes within a given manufacturer shall be cause for Scan Plan revision and may require requalification if any essential transducer parameter is changed.

Material	Thickness	Probe	Wedge
Carbon	Up to 1.5"	5L16-A10	SA10-N55S
		5L32-A11	SA11-N55S
		5L32-A32	SA32-N55S
	Over 1.5"	5L64-A12	SA12-N55S
		5L32-A31	SA31-N55S
		5L32-A32	SA32-N55S
Stainless	Up to 1.0"	5L16-A10	SA10-N55S
		5L16-A1	SA1-N55S
		5DL16-A25	SA25-DN55L
	Over 1"	5L32-A11	SA11-N55S
		5L32-A31	SA31-N55S
		5L32-A32	SA32-N55S
		2.25DM7X4-A17	SA17-DN55L

6.3 Scanners / Encoders

6.3.1 Encoders. Encoding as recognized in this procedure is linear digital encoding (a line scan). Encoding is required for procedure compliance, as provided in the Scan Plan. (See Attachment 1 for MPAUT)

6.3.2 A scanner with built-in mechanical fixturing devices for each probe shall be used for all encoded examinations.

6.4 Couplant

6.4.1 Couplants having good wetting characteristics shall be used. Examples are water, glycerin, and cellulose gum solutions. The same couplant shall be used for calibrations and the examination.

6.4.2 Rust inhibitors, softeners and wetting agents may be added to the couplant, if needed.

6.4.3 The couplant, including additives, shall not be detrimental to the material being examined.

6.4.3.1 Couplants used on nickel-based alloys shall not contain more than 250 ppm of sulfur.

6.4.3.2 Couplants used on austenitic stainless steel or titanium shall not contain more than 250 ppm of halides (chlorides plus fluorides).

6.5 Calibration and Reference Blocks

6.5.1 Basic Calibration Blocks - Calibration blocks that are used to establish DAC/TCG curves and/or sensitivity shall conform to the following requirements.

6.5.2 Block Materials

6.5.2.1 Similar Metal Welds. The material from which the block is fabricated shall be of the same product form and material specification or equivalent P-Number grouping as one of the materials being examined. For the purposes of this paragraph, P-Nos. 1, 3, 4, 5A through 5C, and 15A through 15F materials are considered equivalent.

6.5.2.2 Dissimilar Metal Welds. The material selection shall be based on the material on the side of the weld from which the examination will be conducted. If the examination will be conducted from both sides, calibration reflectors shall be provided in both materials.

6.5.2.3 Transfer Correction. When the block material is not of the same product form or has not received the same heat treatment, it may be used provided it meets all other block requirements and a transfer correction for acoustical property differences is used. Transfer correction shall be determined by noting the difference between the signal response, using the same transducers and wedges to be used in the examination, received from either:

- A. The corresponding reference reflector (same type and dimensions) in the basic cal block and in the component to be examined, or
- B. Two search units positioned in the same orientation on the basic calibration block and component to be examined.
- C. The examination sensitivity shall be adjusted for the difference.

6.5.3 **Quality. Prior to fabrication, the block material shall be completely examined with a straight beam search unit. Areas that contain an indication exceeding the remaining back-wall reflection shall be excluded from the beam paths required to reach the various calibration reflectors.**

6.5.4 Cladding

6.5.4.1 Block Selection. The material from which the block is fabricated shall be from one of the following:

16 Nozzle dropout from the component.

- B. A component prolongation.
- C. Material, including integral clad, of the same material specification, product form, and heat treatment condition as the material to which the search unit is applied during the examination.

- 6.5.4.2 Where the component material is clad and the cladding is a factor during examination; the block shall be clad to at least the same thickness as the part to be examined. Deposition of clad shall be by the same method as used to clad the component to be examined. When the cladding method is not known or the method of cladding used on the component is impractical for block cladding, deposition of clad may be by the manual method.
- 6.5.4.3 When the parent materials on opposite sides of a weld are clad by different P-, A-, or F-numbers or material designations or methods, the calibration block shall be clad with the same P-, A-, or F-numbers or material designations using the same method used on the side of the weld from which the examination will be conducted. When the examination is conducted from both sides of the weld, the calibration block shall provide for calibration for both materials and methods of cladding. For welds clad with a different material or method than the adjoining parent materials, and it is a factor during the examination, the calibration block shall be designed to be representative of this combination.
- 6.5.5 Heat Treatment - The calibration block shall receive at least the minimum tempering treatment required by the material specification for the type and grade. If the calibration block contains welds other than cladding, and the component weld at the time of examination has been heat treated, the block shall receive the same heat treatment.
- 6.5.6 Surface Finish - The finish on the surface of the block shall be representative of the surface finish on the part to be examined.
- 6.5.7 Block Curvature.
- 6.5.7.1 Materials with Diameters Greater Than 20-inches. For examinations in materials where the examination surface diameter is greater than 20-inches, a single curved basic calibration block may be used to calibrate the examinations on surfaces in the range of curvature from 0.9 to 1.5 times the basic calibration block diameter. Alternatively, a flat basic calibration block may be used.
- 6.5.7.2 Materials with Diameters 20-inches and less. For examinations in materials where the examination surface diameter is equal to or less than 20-inches, a curved block shall be used. Except where otherwise stated in this procedure, a single curved basic calibration block may be used for examinations in the range of curvature from 0.9 to 1.5 times the basic calibration block diameter.
- 6.5.7.3 For example, an 8 in diameter block may be used to calibrate for examinations on surfaces in the range of curvature from 7.2-inches to 12-inches in diameter. The curvature ranges from 0.94-inches to 20-inches in diameter requires 6 curved

blocks as shown in Fig. T-434.1.7.2 for any thickness range.

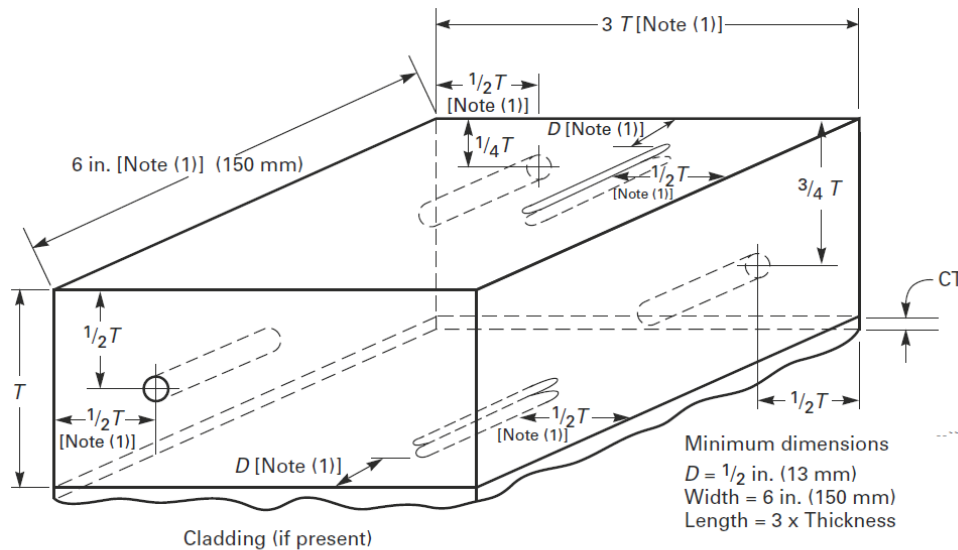
6.5.8 Basic Non-Piping Calibration Blocks

6.5.8.1 The basic calibration block configuration and reflectors shall be as shown in Figure T-434.2.1.

6.5.8.2 The block size and reflector locations shall be adequate to perform calibrations for the beam angle(s) and distance range(s) to be used.

6.5.8.3 Block Thickness. The block thickness (T) shall be per Figure T-434.2.1.

**Figure T-434.2.1
Nonpiping Calibration Blocks**



Notch Dimensions, in. (mm)

Notch depth = 1.6% T to 2.2% T
 Notch width = 1/4 (6) max.
 Notch length = 1 (25) min.

Weld Thickness (t), in. (mm)	Calibration Block Thickness (T), in. (mm)	Hole Diameter, in. (mm)
≤1 (≤25)	3/4 (19) or t	3/32 (2.5)
>1 (>25) through 2 (50)	1 1/2 (38) or t	1/8 (3)
>2 (>50) through 4 (100)	3 (75) or t	3/16 (5)
>4 (>100)	t ±1 (25)	[Note (2)]

GENERAL NOTES:

- (a) Holes shall be drilled and reamed 1.5 in. (38 mm) deep minimum, essentially parallel to the examination surface.
- (b) For components equal to or less than 20 in. (500 mm) in diameter, calibration block diameter shall meet the requirements of T-434.1.7.2. Two sets of calibration reflectors (holes, notches) oriented 90 deg from each other shall be used. Alternatively, two curved calibration blocks may be used.
- (c) The tolerance for hole diameter shall be ±1/32 in. (0.8 mm). The tolerance for hole location through the calibration block thickness (i.e., distance from the examination surface) shall be ±1/8 in. (3 mm).
- (d) For blocks less than 3/4 in. (19 mm) in thickness, only the 1/2 T side-drilled hole and surface notches are required.
- (e) All holes may be located on the same face (side) of the calibration block, provided care is exercised to locate all the reflectors (holes, notches) to prevent one reflector from affecting the indication from another reflector during calibration. Notches may also be in the same plane as the inline holes (see Nonmandatory Appendix J, Figure J-431). As in Figure J-431, a sufficient number of holes shall be provided for both angle and straight beam calibrations at the 1/4 T, 1/2 T, and 3/4 T depths.
- (f) When cladding is present, notch depth on the cladding side of the block shall be increased by the cladding thickness, CT (i.e., 1.6% T + CT minimum to 2.2% T + CT maximum).
- (g) Maximum notch width is not critical. Notches may be made by EDM or with end mills up to 1/4 in. (6.4 mm) in diameter.
- (h) Weld thickness, t, is the nominal material thickness for welds without reinforcement or, for welds with reinforcement, the nominal material thickness plus the estimated weld reinforcement not to exceed the maximum permitted by the referencing Code Section. When two or more base material thicknesses are involved, the calibration block thickness, T, shall be determined by the average thickness of the weld; alternatively, a calibration block based on the greater base material thickness may be used provided the reference reflector size is based upon the average weld thickness.

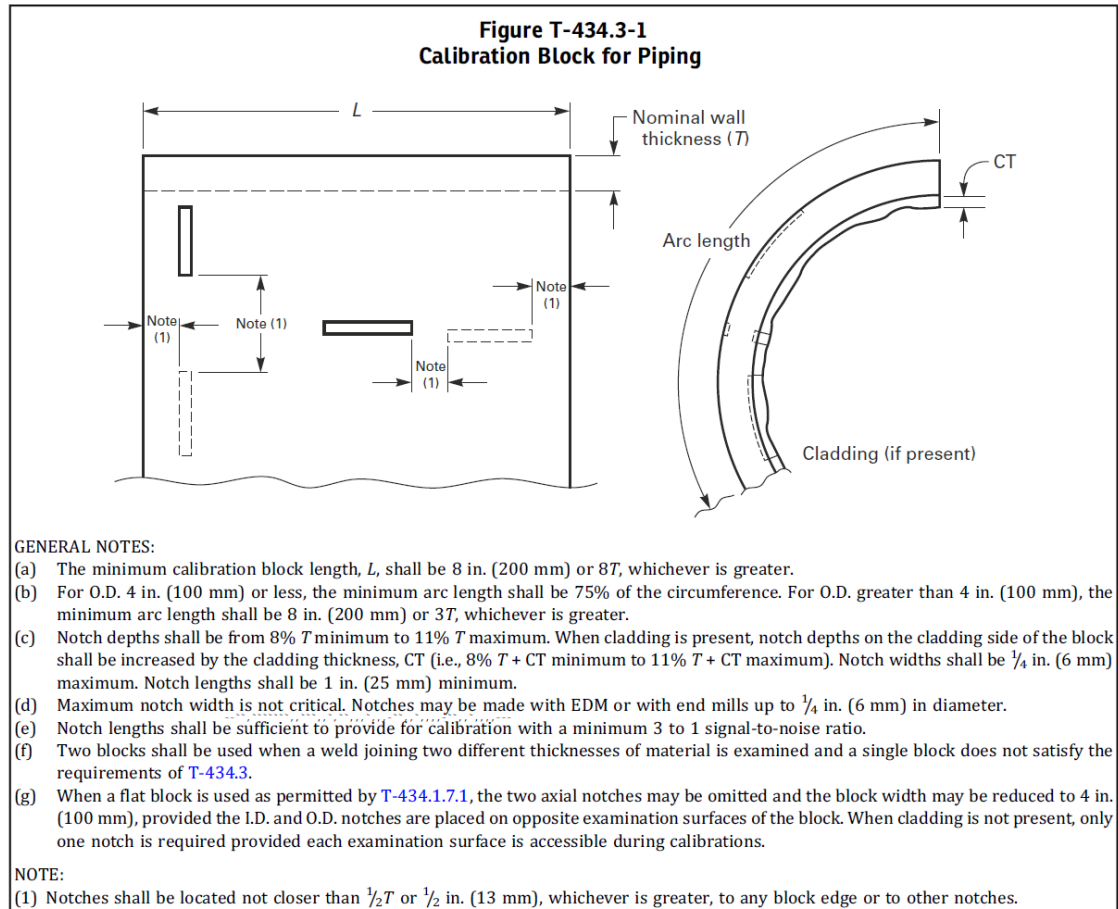
NOTES:

- (1) Minimum dimension.
- (2) For each increase in weld thickness of 2 in. (50 mm) or fraction thereof over 4 in. (100 mm), the hole diameter shall increase 1/16 in. (1.5 mm).

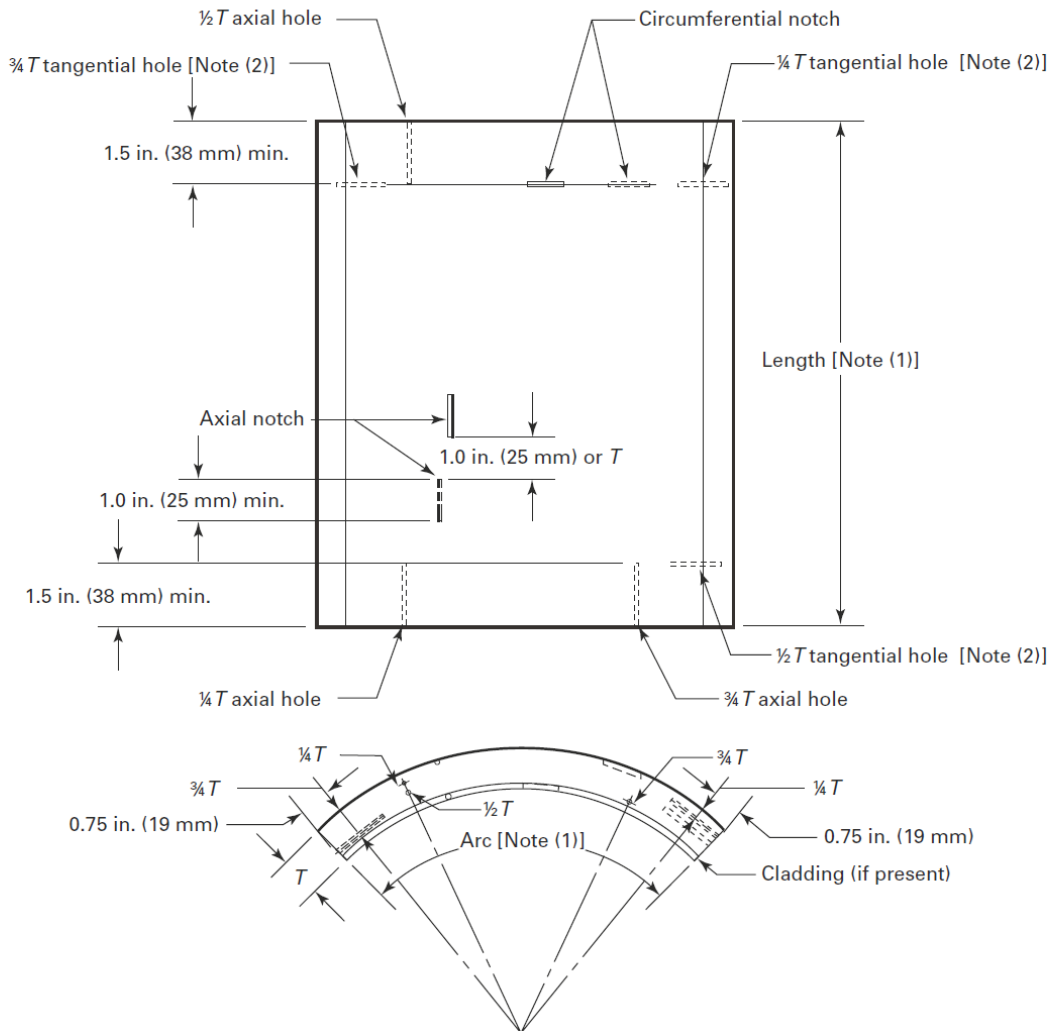
6.5.9 Basic Piping Calibration Blocks.

6.5.9.1 The basic calibration block configuration and reflectors shall be as shown in Figure T-434.3-1 or the alternate provided in Figure T-434.3-2 where curvature and/or wall thickness permits. The basic calibration block curvature shall be in accordance with paragraph 6.5.7. Thickness, T , shall be $\pm 25\%$ of the nominal thickness of the component to be examined.

6.5.9.2 The block size and reflector locations shall be adequate to perform calibrations for the beam angle(s) and distance range(s) to be used.



**Figure T-434.3-2
Alternate Calibration Block for Piping**



GENERAL NOTES:

- (a) For blocks less than $\frac{3}{4}$ in. (19 mm) in thickness, only the $\frac{1}{2}T$ side drilled hole is required..
- (b) Inclusion of notches is optional. Notches as shown in Figure T-434.3-1 may be utilized in conjunction with this calibration block.
- (c) Notch depths shall be from $8\% T$ minimum to $11\% T$ maximum. Notch widths shall be $\frac{1}{4}$ in. (6 mm) maximum. Notch lengths shall be 1 in. (25 mm) minimum.
- (d) Notches may be made with EDM or with end mills up to $\frac{1}{4}$ in. (6 mm) in diameter.
- (e) Notch lengths shall be sufficient to provide for calibration with a minimum 3 to 1 signal-to-noise ratio.
- (f) Notches shall be located not closer than T or $1\frac{1}{2}$ in. (38 mm), whichever is greater, to any block edge or to other notches.

NOTES:

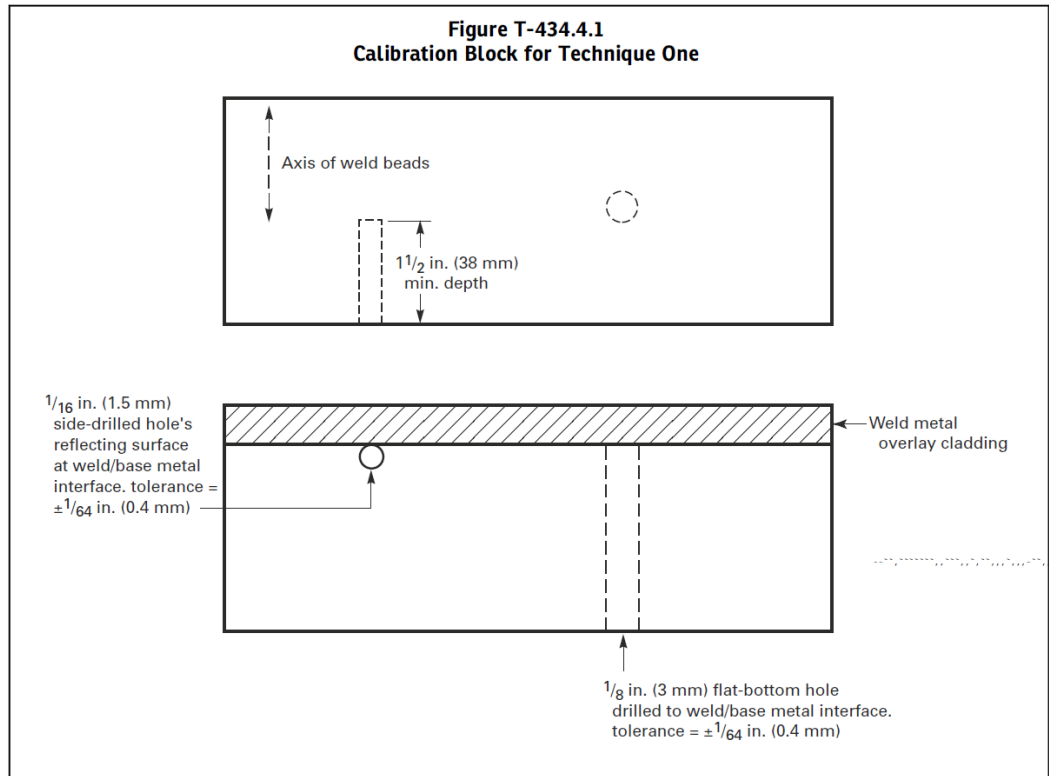
- (1) Length and arc shall be adequate to provide required angle beam calibration.
- (2) Side-drilled hole diameter, length, and tolerance shall be in accordance with T-434.2.1, as permitted by T-464.1.3. Tangential side-drilled holes at $\frac{1}{4}T$, $\frac{1}{2}T$, and $\frac{3}{4}T$ positions or locations are to have the depth confirmed at one-half of their length. The radius of the side-drilled hole shall be added to the measured depth to ensure the correct depth. Where thickness does not permit, the required depth of the side-drilled hole and the location of the tangential position shall be indicated on the block surface.

6.5.10 Weld Metal Overlay Cladding Calibration Blocks. (Technique One)

6.5.10.1 The basic calibration block configuration and reflectors shall be as shown in Figure T-434.4.1. Either a side-drilled hole or flat bottom hole may be used.

6.5.10.2 The thickness of the weld metal overlay cladding shall be at least as thick as that to be examined. The thickness of the base material shall be at least twice the thickness of the weld metal overlay cladding.

6.5.10.3 The block curvature shall be in accordance with section 6.5.7.

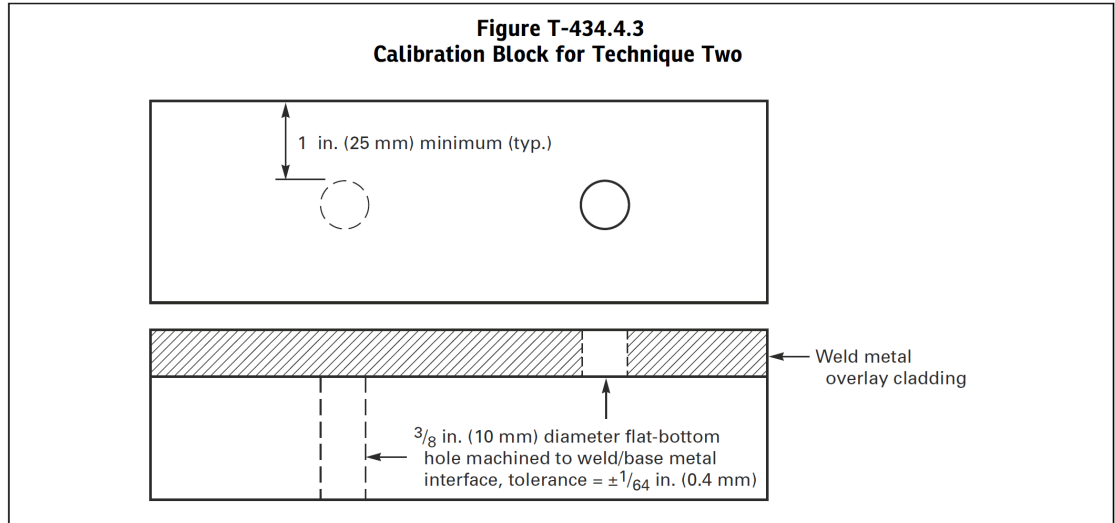


6.5.11 Weld Metal Overlay Cladding Calibration Blocks. (Technique Two)

6.5.11.1 The basic calibration block configuration and reflectors shall be as shown in Figure T-434.4.3. A flat bottom hole drilled to the weld/base metal interface shall be used. This hole may be drilled from the base material or weld metal overlay cladding side.

6.5.11.2 The thickness of the weld metal overlay cladding shall be at least as thick as that to be examined. The thickness of the base material shall be within 1.0 inch of the calibration block thickness when the examination is performed from the base material surface. The thickness of the base material on the calibration block shall be at least twice the thickness of the weld metal overlay cladding when the examination is performed from the weld metal overlay cladding surface.

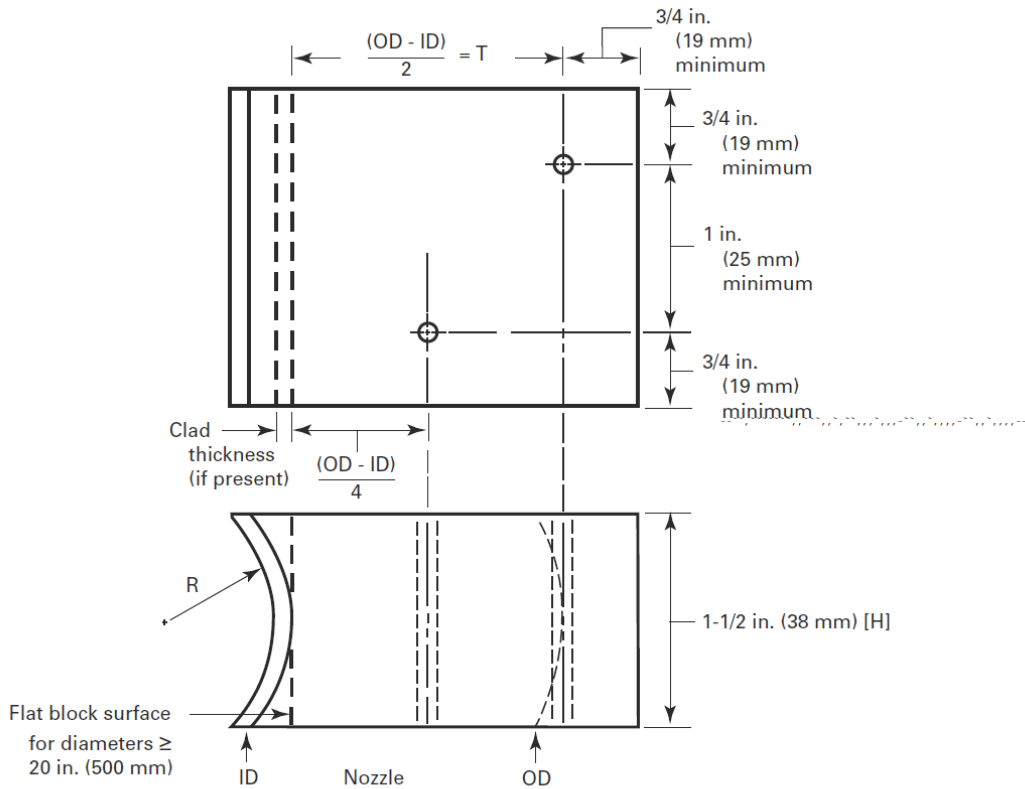
6.5.11.3 The block curvature shall be in accordance with section 6.5.7.



6.5.12 Nozzle Side Weld Fusion Zone and/or Adjacent Nozzle Parent Metal Calibration Blocks.

6.5.12.1 Configuration. The calibration block configuration shall be as shown in Figure T-434.5.1. The block size and reflector locations shall be adequate to perform calibrations to cover the nozzle parent metal. If the internal surface of the nozzle is clad before the examination, the ID surface of the calibration block shall be clad.

Figure T-434.5.1
Calibration Block for Straight Beam Examination of Nozzle Side Weld Fusion Zone and/or Adjacent Nozzle Parent Metal



GENERAL NOTES:

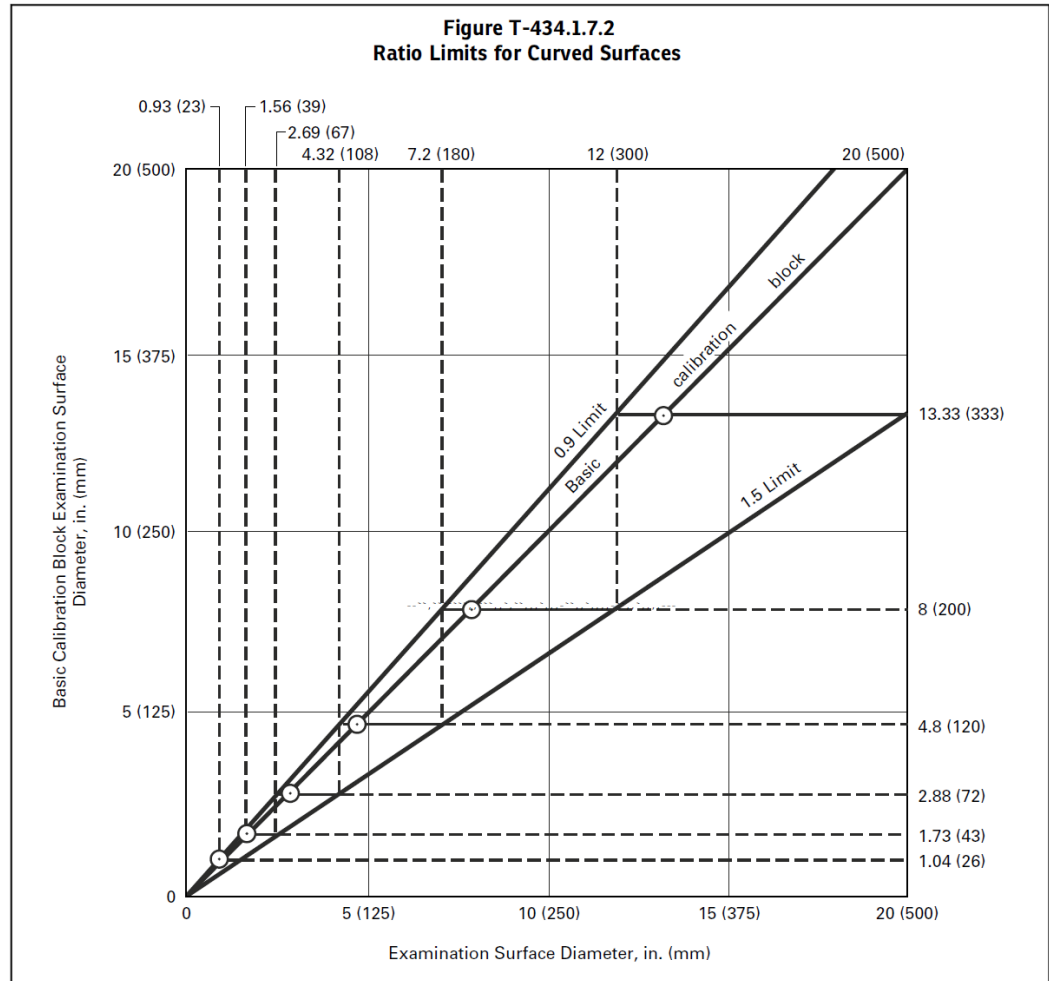
- (a) The thickness, T , of the calibration block $(O.D. - I.D.)/2$ shall be selected for the maximum nozzle wall thickness under the nozzle attachment weld.
- (b) Side-drilled holes shall be drilled and reamed the full height, H , of the block.
- (c) The diameter of the side-drilled holes shall be selected for the maximum nozzle wall thickness per (a) above and [Figure T-434.2.1](#).
- (d) For nozzle side examinations, when the wall thickness of the calibration block exceeds 2 in. (50 mm), additional side-drilled holes shall be placed in the block as required in the table below.

Calibration Block Wall Thickness, in. (mm)	Hole Location, $\frac{5}{8}T$	Hole Location, $\frac{3}{4}T$	Hole Location, $\frac{7}{8}T$
>2 (>50) through 3 (75)	...	X	...
>3 (>75)	X	X	X

6.5.12.2 Block Thickness. The calibration block shall be the

maximum thickness of the nozzle wall adjacent to the nozzle weld plus 3/4 in.

6.5.12.3 Curvature. For examinations of nozzles with an inside diameter (I.D.) equal to or less than 20 in., the contact surface of the calibration block shall have the same curvature or be within the range of 0.9 to 1.5 times the diameter as detailed in Figure 434.1.7.2.



6.5.12.4 Calibration Reflectors. The calibration reflectors shall be side-drilled hole(s) that are in accordance with the requirements of Figure T-434.2.1 for the nozzle wall thickness.

6.5.12.5 Alternative Blocks. Alternative calibration blocks may be used for similar types of examinations provided the sound path distance(s) to the block's reflector(s) is(are) within 1/4 in. of what is required and the side drilled hole(s) is(are) the same or a smaller diameter than what is required.

6.5.13 Reference Blocks (i.e., IIW, DSC, Rompas, etc.) used for establishing linear screen ranges and determining actual refracted angle and exit

point information shall be made of a material that meets the requirement of paragraph 6.5.2.1.

- 6.5.13.1 Reference blocks used for performing calibration verifications (calibration checks) may be made of any suitable material if adequate sweep and amplitude verification points can be established.
- 6.5.14 Scanner Block - A scanner block shall be used which meets all the material requirements listed in 6.5.2 through 6.5.7 and its thickness (T), shall be within the lesser of $\frac{1}{4}$ -inch or 25% of the material to be tested.
 - 6.5.14.1 This block shall be of sufficient size to allow for a dynamic calibration of the test system utilizing the calibration reflectors required in 6.5.8.
 - 6.5.14.2 The number and position of the side-drilled holes shall be adequate to confirm the sensitivity setting of each probe, as positioned per the scan plan in the scanner.
 - 6.5.14.3 This block may be used as a replacement for the basic calibration block provided all the requirements in 6.5.2 through 6.5.7 are met. The basic block described in 6.5.8 may be used as the scanner block if the configuration allows for it to be scanned.
- 6.5.15 Supplemental Block - due to the nature of the phased array systems, supplemental blocks may be necessary to achieve sufficient establishment of the required sizing curves by spacing out the calibration reflectors. NAVSHIP or PAC® (Phased Array Calibration Standards) may be used provided the material requirements of 6.5.2 are met. The preliminary reference level gain shall then be adjusted off of a block which meets all the requirements of 6.5.8 for pressure vessel welds or the requirements for 6.5.9 for piping weld examinations.

7.0 SCAN PLAN REQUIREMENTS

- 7.1 A scan plan (documented examination strategy) shall be developed for each weld joint type and thickness that shows equipment set-ups, search unit placements and movements and provides a standardization and repeatable methodology for the examination. The scan plan may be handwritten or developed using computer simulation software such as ES Beam Tool.
 - 7.1.1 Contents - In addition to the information in Table IV-421 of this procedure, the scan plan shall include beam angles and directions with respect to the weld axis reference point, weld joint geometry, and number of examination areas or zones.
 - 7.1.2 Personnel -The scan plan shall be developed by Level II or III individuals meeting the qualification requirements of Section 5.0.

7.2 Examination Volume or Area of interest.

7.2.1 Weld Examinations

- 7.2.1.1 Unless otherwise specified in the applicable codes or project specific documents, the examination volume or area of interest for weld examinations, shall be the weld, plus the lesser of the nominal thickness or 1.0 inch on each side of the weld.
- A. In the case of B31.3 High Pressure Piping welds, the examination volume or area of interest shall include the volume of the weld, plus 2.0 inches on each side of the weld.
- 7.2.1.2 Scan Plan - Weld profile and component thickness information shall be obtained prior to calibration to determine examination coverage and technique selection. The range of examination angles shall be determined which will provide complete coverage of the weld, heat affected zone, and the adjacent base material, as appropriate for the configuration being examined.
- 7.2.1.3 Special consideration shall be given to geometric conditions such as non-parallel surfaces (i.e., counter bore and OD taper transition areas), weld shrinkage (i.e., hoop shrinkage areas in the base metal heat affected zone), and/or "as welded" if weld crowns are present.
- 7.2.1.4 A Scan Plan shall be required for both Encoded PAUT as well as MPAUT.
- 7.3 Transducer Positioning
- 7.3.1 Butt Welds - All butt welds shall be scanned by the linear (line scanning) technique parallel to the weld seam with the probes at constant standoff distance. The examination shall be performed from both sides of welds unless physically impossible.
- 7.3.2 Dual Side Access Butt Joints - All butt welds shall be scanned from both sides of the weld joint wherever physically possible. Welds scans shall be identified according to their appropriate skew angle (90 versus 270) in a documented system to enable repeatability. In piping, the upstream side of the weld shall be labeled as the 90 side. The downstream side of the joint shall be identified as the 270 side.
- 7.3.3 Single Side Access Butt Joints - butt welds that cannot effectively be scanned from both sides shall be scanned using the enhanced single side (ESSA) technique. This includes the parallel line scan from the accessible side of the joint combined with a manual raster scan looking for transverse flaws.
- 7.3.4 Nozzle Welds and Branch Attachment Welds - the primary scans of vessel nozzles and branch attachments welds, shall occur from the primary (beveled) surface and on the non-beveled surface using an angle beam technique in accordance with this section. In addition, a straight beam technique from the ID of the non-beveled plate surface may be beneficial but not required by procedure. Nozzles shall be manually scanned per the requirements of Attachment 1 of this procedure.

- 7.4 Focal Law Requirements
- 7.4.1 Wave Modes - Shear waves shall be utilized for all examinations unless material grain size or structure prohibits calibration of the ultrasonic examination. If refracted L-waves must be utilized to allow calibration and sufficient penetration through the test material, all weld reinforcement shall be ground flush as the examination will be limited to the first leg.
- 7.4.2 Focal Law Sequence Types - S Scans (Sectorial Scans), E Scans (Linear Scans), or a combination of both may be utilized for the examination provided that the following requirements are met.
- 7.4.2.1 Sectorial Scan (Azimuthal) Requirements
- A. Element quantity shall be configured between 10 and 32 elements.
 - B. The angular sweep incremental change shall be a maximum of 1 degree.
 - C. Beam angles shall be configured to be within the limits of the wedge manufacturer and shall be within the angles of 35° to 75°.
- 7.4.2.2 Electronic Scan (Linear Scan) Requirements
- A. Use of linear scans is limited to transducers with 60 or more elements.
 - B. 12 to 32 elements shall be activated for each individual aperture.
 - C. A maximum element step of 2 may be utilized.
 - D. Beam angles shall be configured to be within the limits of the wedge manufacturer and shall be within the angles of 0° to 60°.
- 7.4.3 Focal Depth - Focus depths may be set at the depth of the first calibration reflector to be utilized in the TCG establishment when element quantity configurations are between 10 and 16 elements. If more elements are used or if focusing results in poor sound pressure during calibration, the focal depth shall be set at 3 times the material thickness or 10 inches, whichever is less. Additional focusing may be implemented during applicable manual techniques, if necessary, to aid in specific evaluations of indications.
- 7.5 Scan Set-Ups - Scan planning shall show coverage of the full weld volume and HAZ as described in 7.2.1.1. The following guidelines shall be used to establish adequate weld coverage.
- 7.5.1 Dedicated Root Scan - The first group of focal laws on each side of the weld joint shall be established to inspect the root area of the weld by means of a sectorial scan.
- 7.5.1.1 For single V joints, the location of the 60° beam should be near the center of the root area to ensure complete coverage of the root area.
- 7.5.1.2 For double v joints, higher angles (65 to 75 degrees) should be configured to cover the entire root area of the weld.

- 7.5.2 Additional Groups - additional groups of scans may be established and shall be of a sufficient number and nature to provide the coverage requirements of paragraph 7.2.1.1. These groups may be combinations of S-Scans or mixtures of S-Scans and E-Scans. A minimum overlap of 10% of the effective aperture height for E-Scans (Linear Scans) or beam width for S-Scans (Sectorial Scans), shall be employed for multiple groups used to provide full zonal coverage of the weld and fusion-face areas.
- 7.5.3 Fusion Face Coverage- Beams shall be configured so that the ultrasonic beam intersects the weld-base metal interface within -10° to $+10^{\circ}$ of perpendicular for S-scans and -5° to $+5^{\circ}$ of perpendicular for E-Scans whenever possible. This may be accomplished with multiple sectorial or linear scans, if necessary, to cover the entire fusion face.
- 7.5.4 HAZ Coverage - The heat affected zone, as described in 7.2.1.1, shall be covered with angles between 40 and 60 degrees.
- 7.5.5 Index Point(s) - Based on demonstration of this procedure, a single index position may be utilized for dual side access examinations of materials with thicknesses up to 0.500". For all single side access or dual side access on materials greater than 0.500", a minimum of two indexes shall be performed on each accessible side of the weld. Indexing may be accomplished by multiple physical index positions or two electronic index positions (i.e., grouping). The requirements of 7.5.2 shall apply to all additional indexes.
- 7.5.5.1 When physical indexing is performed, the scans closest to the weld shall be identified as 90-1 and 270-1 scans. Each additional index point shall be identified with sequential numbers (Example: 90-2 and 270-2).

8.0 CALIBRATION REQUIREMENTS

- 8.1 Calibrations shall include the complete ultrasonic system and shall be performed prior to use of the system in the thickness range under examination using the same couplant and wedges to be used during the examination. A new calibration shall be performed if any focal law parameter is changed. In addition, calibration shall be verified in accordance with paragraph 8.16 if any essential variable is changed.
- 8.2 Transducer Element Operability- Prior to daily use, the transducer shall be checked for "dead" elements. Instructions for this check can be found in Attachment 3.
- 8.3 Wedge Condition - Prior to daily use, the wedge shall be visually examined to ensure that it has not been worn excessively or unevenly such that the calibrations in paragraph 8.10 cannot be performed.
- 8.3.1 A flat wedge may be used for calibrations in place of a curved wedge provided the following criteria are met.

- 8.3.1.1 The curved wedge is to be used on circumferential (girth) welds.
- 8.3.1.2 The wedge model and type are the same.
- 8.3.1.3 No visible wear is present on either wedge (IHC brackets and carbides should be used wherever possible to prevent wear).
- 8.3.1.4 The curved wedge is used to establish reference level sensitivity per paragraph 8.13 of this procedure and used in conformation per section 8.18.
- 8.4 Calibration Block - The calibration block selected shall meet the requirements of paragraph 6.5. Calibrations shall be performed from the surface (clad or unclad; convex or concave) corresponding to the surface of the component from which the examination will be performed. The temperature differential between the calibration block and examination surfaces shall be within 25°F.
- 8.5 Ultrasonic System. Calibrations shall include the complete ultrasonic system and shall be performed prior to use of the system in the thickness range under examination.
- 8.6 Calibration Surface. Calibrations shall be performed from the surface (clad or unclad; convex or concave) corresponding to the surface of the component from which the examination will be performed.
- 8.7 Couplant. The same couplant to be used during the examination shall be used for calibration.
- 8.8 Contact Wedges. The same contact wedges to be used during the examination shall be used for calibration.
- 8.9 Instrument Controls. Any control which affects instrument linearity (e.g., filters, reject, or clipping) shall be in the same position for calibration, calibration checks, instrument linearity checks, and examination.
- 8.10 UT Range Setting - The UT range of the examination shall be set to show the entire area and/or weld volume to be examined. Considerations for this adjustment shall include:
 - 8.10.1 TCG Curve - The UT range shall be set with regard to the 1st and last point on the TCG curve to cover the entire area and/or weld volume to be examined. Both points shall be included in the UT range.
 - 8.10.2 Coverage -The UT range shall be set based on the coverage area the beam set/group was scan planned to cover.
- 8.11 Pulse Repetition Rate - the PRF shall be set to assure that a reflector located at the maximum distance of the examination will arrive back to the search unit before the next pulse is sent. Issues with PRF can be seen in the S-Scan image in phased array and this setting is directly related to maximum scan speed.
- 8.12 Filter Settings - Video filters shall be set in the off position. Narrow band or broad band receiver filters may be used but these settings shall not be altered after calibration is performed.
- 8.13 Calibration - All calibration requirements listed in section 7.0 and section 8.0

shall be performed for every configured sound beam within each beam set.

- 8.14 Angle Beam Calibration - The same focal law configuration, wedges, and UT parameters which effect linearity and used in calibration shall also be used during examination. Every configured beam angle shall be calibrated in accordance with the following:

8.14.1 Time-Base Calibration - The time-base shall be calibrated using a supplemental calibration block (NAVSHIP or PACs block) of the same material type as detailed in paragraph 6.5.2. The time-base calibration shall consist of calibration or verification of the material velocity and wedge delay as follows:

8.14.1.1 Velocity Verification/Calibration: The nominal velocity shall be inputted in the UT Settings menu for the material and wave mode being utilized. The velocity shall be verified by moving the transducer left and right over the side drilled holes in the NAVSHIP or PACS block. Velocity shall be considered adequate if the signal travels horizontally across the S-scan image. If the signal exhibits diagonal movement, slight velocity adjustments shall be made until the signal walks in a horizontal manner.

8.14.1.2 Wedge Delay Verification/Calibration: the proper wedge delay shall be verified through all focal laws by scanning left and right over side drilled holes at known depths. Verification can be made using the source/ highest feature or by using the wizard feature. The wedge delay input shall be sufficient to provide depth accuracies with ± 0.040 ".

A. If readings are measured outside these tolerances either a new wedge shall be used, or a correction calibration shall be performed in the wizard.

8.14.2 Angle Corrected Gain (Sensitivity) Calibration - This calibration is not required when a TCG calibration is to be performed. When opted for, each focal law shall be calibrated to within $\pm 5\%$ FSH on a reflector corresponding to the first TCG point.

8.14.3 TCG Establishment: A Time Corrected Gain (TCG) shall be established for each group of scans to be performed and shall cover the entire sound path range to be used during examination. This includes a minimum of 2 full legs for dual sided access scans or 3 full legs for single sided access scans or when examining nozzle or branch attachment welds. The Range shall be adjusted in each group to enable visibility of this entire sound path under examination for all angles.

8.14.3.1 Calibration shall begin with the reference reflector near the depth where sound enters the area of interest.

8.14.3.2 The TCG shall be set so that the response for each side drilled hole (in depth up to 3 times the part thickness to be examined) equals 80%, $\pm 5\%$ of FSH.

8.14.4 Transfer Correction. When the block material is not of the same product form or has not received the same heat treatment, it may be used provided it meets all other block requirements and a transfer correction for acoustical property differences is used. Transfer correction shall be determined by noting the difference between the signal response, using the same transducers and wedges to be used in the examination, received from either:

8.14.4.1 The corresponding reference reflector (same type and dimensions) in the basic calibration block and in the component to be examined, or

8.14.4.2 Two search units positioned in the same orientation on the basic calibration block and component to be examined.

8.14.4.3 The sensitivity shall be adjusted for the difference.

8.14.5 Reference Level Sensitivity Establishment - After the TCG is established, the ASME calibration/scanner block as described in paragraph 6.5 and paragraph 8.14.3.2, shall be scanned and the dB adjusted to set preliminary reference level at the applicable screen height in an "in-motion" calibration. The primary reference level sensitivity shall be this dB level + any required transfer correction.

8.14.5.1 For Sectorial Scans, the reference level shall be established off a median angle (i.e., 60 degrees in a 40 to 70-degree sectorial scan. For E-scans, any VPA may be used.

8.14.5.2 The Primary reference level sensitivity shall be TCG + Preliminary Reference Level Sensitivity + Transfer Correction.

8.15 Straight Beam Calibration

8.15.1 Time-Base Calibration -The time-base shall be calibrated/ verified as follows:

8.15.1.1 Velocity- Using a thickness gauge, calibrate on a step wedge covering the entire thickness range to be evaluated and input the velocity measurement obtained afterward in the Sonatest Prisma. OR using the configured PAUT setup, calibrate on the step wedge or known material thickness of the same material type using the Sonatest Prisma Calibration.

8.15.1.2 Wedge Delay - A wedge delay calibration shall be performed using the Sonatest Prisma Calibration after the velocity is inputted. The wedge delay shall be performed on the step wedge or known material thickness with parallel surfaces. The depth of the back-wall used for calibration shall be at or near the nominal part thickness to be examined.

A. The wedge delay for O degree examinations shall be accurate to within 0.039.

8.15.2 TCG Calibration – If Straight Beam examination is used for weld volume examination, a TCG curve shall be established in accordance with paragraph 8.14.3 with holes at depths to completely cover the

weld volume and HAZ area to be inspected. For lamination scans, a manual TCG shall be installed setting the first and second back-walls of the part to be examined at approximately 80% FSH.

8.15.3 Reference Level Establishment - For weld volume examinations, the reference level shall be established off the calibration block type and reflector as detailed in 6.5.8 and 6.5.9, as well as the transfer correction, as applicable. For lamination scans, place the search unit on a defect free portion of the material and adjust the gain to set the first and second back-walls at approximately 80 to 100% FSH.

8.16 Calibration and Scan Plan Verification -The scanner block or calibration block shall be scanned per 6.5.8 and/or 6.5.9 and the reference reflector indications recorded to confirm system calibration prior to and at the completion of each examination or series of examinations, when examination personnel are changed, and if the scan plan is required to be modified. If any focal law parameter is changed, a completely new calibration shall be performed. The following requirements shall apply to verification scans performed after the first calibration.

8.16.1 Verification Requirements -The following requirements shall apply to verification scans performed after the first calibration.

8.16.1.1 Sweep Range Correction - If a point on the TCG curve has moved on the sweep line more than 10% of the sweep reading or 5% of full sweep, whichever is greater, the sweep range calibration shall be corrected, and the correction noted in the examination record. All recorded indications since the last valid calibration or calibration check shall be re-examined with the corrected calibration and their values shall be changed on the data sheets.

8.16.1.2 TCG Correction - If a point on the curve has changed by more than 20% or 2 dB of its amplitude, correct the sensitivity calibration, and note the correction in the examination record.

8.16.1.3 If any of the points on the curve has decreased more than the above values, all data sheets since the last valid calibration check shall be marked void and the area covered by the voided data shall be reexamined.

8.16.1.4 If any of the points on the curve has increased more than the above values, all recorded indications since the last valid calibration or calibration check shall be reexamined with the corrected calibration and their values shall be changed on the data sheets.

8.17 Encoder Calibration - A calibration check shall be performed prior to daily use by moving the encoder a minimum distance of 20-inches. The display distance shall be within 1% of the actual distance moved. (0.2-inches tolerance over a 20-inches long scan). The encoder linearity shall be monitored throughout each day's use and recalibrated if necessary.

8.18 Set-Up Files - The set-up file, including all calibrations, shall be established

and saved electronically by the scan plan developer or other personnel as qualified in accordance with section 5.0. In all cases the scan plan developer shall review the final setups and calibrations to verify compliance with the written scan plan. This shall be known as the first calibration and is to allow repeatability during examination.

9.0 EXAMINATION REQUIREMENTS

9.1 Pre-Examination

9.1.1 Prior to the examination, Scan Plan (weld profile and component thickness information), prepared per section 7.0, shall be reviewed, and compared to the “as-found” configuration and required by section 7.0.

9.1.1.1 This review is intended to validate the examination technique and provide information on any changes or limitations to the examination.

9.2 Scanning shall be performed on the surface of the test piece that corresponds to the scanning surface on the scan plan.

9.3 Identification of Weld Examination Areas

9.3.1 Weld Locations. Weld locations and their identification shall be recorded on a weld map or in an identification plan.

9.3.2 Permanent marking of components should be the responsibility of the manufacturer unless otherwise agreed upon in the contract documents.

9.3.3 Reference Point Marking: All scan start and stop locations (X-circ, & Y-axial) shall be based on absolute coordinates.

9.4 Surface Preparation - Surfaces shall correspond to that of the scanner block. In general, satisfactory results may be obtained when the surface of the part is in the as-rolled, as-welded, or as-forged condition. However, surface preparation by grinding, machining or other methods may be necessary where surface irregularities could mask indications of discontinuities.

9.5 Prior to ultrasonic examinations, the surface to be examined and the adjacent area within 1.00 inch, shall be cleaned and shall be free of any rust, scale, welding flux, spatter, grease, paint, oily film, dirt, or other extraneous material that could obscure openings or otherwise interfere with the examination.

9.6 Mechanical cleaning of test surfaces using power wire brushes, power grinders or sand or grit blast operations may reduce the sensitivity of the test and shall be performed with appropriate caution.

9.6.1 The use of hand scrapers, plastic abrasive pads, hand brushes, and similar types of mechanical cleaning are permissible, and may be accompanied using of solvent Cleaner/Remover.

9.6.2 When solvent Cleaner/Removers are used, control of contaminants

- must be observed.
- 9.6.2.1 A Certified Material Test Report (CMTR) shall be obtained for all Cleaner/Remover's materials used on nickel-based alloys, austenitic or duplex stainless steels, and titanium.
 - 9.6.2.2 The total residual amount of sulfur and halogens shall not exceed one percent by weight or 250 ppm.
 - 9.6.2.3 Contour grinding or machining on the weld reinforcement shall only be permitted when approved by the Client.
 - 9.6.3 Any weld crown condition that prohibits adequate volumetric coverage from the base material surface in either the axial or circumferential directions shall be documented on the UT report.
- 9.7 Evaluation of Laminar Reflectors - Prior to performing any angle beam examinations, a straight beam examination shall be performed on the volume of the base material through which the angle beams will travel to locate any reflectors that can limit the ability of the angle beam to examine the weld volume. This examination may be performed manually, as part of a previous manufacturing process, or during the automated UT examination provided detection of these reflectors is demonstrated.
- 9.7.1 Reflectors evaluated as laminar reflectors in the base material, which interfere with the scanning of the examination volume, shall require the scan plan to be modified such that the maximum feasible volume is examined and shall be noted in the examination records.
- 9.8 Parallel Line Scanning (For the Detection of Indications Parallel to the Weld Axis).
- 9.8.1 Linear Encoded Scanning - Each weld shall be scanned as detailed in the applicable scan plan using a fixed linear scan running parallel to the weld axis at a constant stand-off distance, with the beam oriented perpendicular to the weld axis from two opposite directions.
 - 9.8.1.1 This shall be using a semi-mechanized or fully mechanized scanner. All parameters, including focal laws and index points, shall be in accordance with the scan plan. The search unit shall be maintained at a fixed distance from the weld axis by a fixed guide or mechanical means.
 - 9.8.2 Single Side Enhanced Single Side Access Welds - Welds that cannot be examined from both sides of the weld joint for parallel line scanning per the setup requirements of Section 7.0, shall be scanned using an Enhanced Single Side Access technique.
 - 9.8.2.1 In addition, weld joints which allow shall also be examined to the maximum extent possible with a straight beam technique applied from an adjacent base material surface as described in 7.3.3. This may be applicable to tee joints, piping flanges welds, or pipe to fittings. The area(s) of single side access and, if applicable, the extent of the limit coverage shall be noted in the applicable scan plan and examination report.

- 9.8.3 Manual PAUT - Supplemental examinations or MPAUT examinations for non-UT in lieu of RT without the use of an encoder shall be performed in accordance with Attachment 1 of this document.
- 9.8.4 Nozzle Weld Scans
 - 9.8.4.1 When examining nozzle welds, the scans for the detection of indications parallel to the weld axis, shall be performed from the nozzle side of the weld, as well as the shell/head side of the weld.
- 9.8.5 Branch Attachment Weld Scans
 - 9.8.5.1 When examining branch attachment welds, the scans for the detection of indications parallel to the weld axis, shall be performed from the branch attachment side of the weld, as well as the pipe side of the weld.
- 9.9 Transverse Flaw Detection Scanning (For the Detection of Indications Transverse to the Weld Axis) shall be performed as described below using a MPAUT (per Attachment 1).
 - 9.9.1 Butt Welds with Reinforcement: If the weld cap is not ground flush, an examination shall be performed from the base material on both sides of the weld cap and on top of the weld cap.
 - 9.9.2 While scanning parallel to the weld axis, the sound field shall be directed from 0 degrees to 60 degrees with respect to the weld axis in both axial directions, with the sound field passing through the entire examination volume. Scanning on top of the weld shall be performed in two opposing directions.
 - 9.9.2.1 Scanning dB shall be performed at +6dB over primary reference for base metal scanning.
 - 9.9.2.2 For scans on top of the weld reinforcement the scanning shall be +12 dB over primary reference.
 - 9.9.3 Butt Welds without Reinforcement: If the weld cap is machined or ground flat, the examination shall be performed on the weld and the adjacent base material at +6dB over primary reference. While scanning, the sound field shall be directed essentially parallel to the weld axis in both axial directions. The search unit shall be manipulated so that the sound field passes through the required examination volume.
 - 9.9.4 Nozzle and Branch Attachment Weld Scans
 - 9.9.4.1 When examining nozzle welds, the scans for the detection of indications transverse to the weld axis., shall be performed from the nozzle side of the weld, as well as the shell/head side of the weld.
 - 9.9.4.2 When examining branch attachment welds, the scans for the detection of indications transverse to the weld axis., shall be performed from the branch attachment side of the weld, as well as the pipe side of the weld.

9.9.4.3 Scanning on top of the weld is not required when examining nozzle welds.

9.9.5 Circumferential Scans: For circumferential weld scans the following information shall be considered prior to selecting the examination angle for transverse scanning:

9.9.5.1 The examination angle must be equal to or less than the inverse sin of the nominal ID divided by the nominal OD, when examining small diameter/thick wall piping.

$$\theta = \text{Sin}^{-1}\left(\frac{ID}{OD}\right)$$

9.9.5.2 If this calculation identifies a need for an examination angle less than 45°, examinations may be performed utilizing a lower angle. Refracted angles less than 30° should be avoided due to calibration and examination difficulties. It is important to note that for pipe diameters less than 14.0" diameter, the nominal OD is slightly greater than the nominal pipe size.

9.9.5.3 Manual Conventional UT examinations using an approved Manual ASME UT Procedure may also be used to supplement this procedure.

9.10 Coarse Grain Materials - Ultrasonic examinations of high alloy steels and high nickel alloy weld deposits and dissimilar metal welds between carbon steels and high alloy steels and high nickel alloys are usually more difficult than ferritic weld examinations.

9.10.1 Difficulties with ultrasonic examinations can be caused by an inherent course-grained and /or a directionally oriented structure, which can cause marked variations in attenuation, reflection, and refraction at grain boundaries and velocity changes within the grains.

9.10.2 It is necessary to modify and/or supplement the provisions of this Article in accordance with T-150(a) when examining such welds in these materials. Additional items, which are required, are weld mockups with reference reflectors in the weld deposit and single or dual element longitudinal wave transducers.

9.11 Computerized Imaging Techniques. The major attribute of Computerized Imaging Techniques (CITs) is their effectiveness when used to characterize and evaluate indications; however, CITs may also be used to perform the basic scanning functions required for flaw detection.

9.11.1 Computer-processed data analysis and display techniques are used in conjunction with nonautomated scanning, semi-automatic scanning, or automatic scanner technique(s) to produce two and three-dimensional images of flaws, which provides an enhanced capability for examining critical components and structures.

9.11.2 Computer processes may be used to quantitatively evaluate the type, size, shape, location, and orientation of flaws detected with this

procedure.

- 9.12 Data Recording Requirements - The A-scan data shall be set to record for the area of interest in an unprocessed form at a minimum digitization rate of five times the examination frequency, and with a scan resolution of a maximum of:
 - 9.12.1 0.04" for material less than 3" thick.
 - 9.12.2 0.08" for material 3" thick or greater.
- 9.13 Scanning Speed/ Data Drop-Out -Encoded scanning speed shall not exceed the data acquisition rate and such that the data drop-out is less than 2 data lines per inch of the linear scan length and that there are no adjacent data line skips.
- 9.14 Display Settings - The display should be set to visualize the S- and C-Scans at minimum during scanning to enable monitoring of the data collection.
- 9.15 Scanning Sensitivity - When TCG is implemented, scanning may be performed at primary reference level provided soft gain or color pallet enhancements are made during evaluation. Otherwise, the gain level shall be set at 6 dB's higher than the primary reference level during scanning.
- 9.16 Saving Data - At the conclusion of each scan, all original scan data shall be saved on internal storage, external hard drive, USB, flash memory card, or external computer.
- 9.17 Post Examination Cleaning - All couplant shall be removed following the completion of the examination as a precaution to reduce risks of corrosive materials remaining in contact with the examination material. Unless otherwise stipulated by contract documents, a simple dry or water dampened cloth wipe will be sufficient. Caution should be taken before using any type of solvent-based cleaner as some materials could have adverse reactions.
- 9.18 Restricted Access and Inaccessible Welds - Welds that cannot be fully examined as specified in the scan plan due to factors preventing probe access shall be examined from alternate positions and/or angles wherever possible. This may be by manually scanning if necessary. Any areas of restricted access which provide inaccessibility shall be noted in the examination report.

10.0 INTERPRETATION/EVALUATION

- 10.1 Final evaluation shall only be made after all display parameters adjustments (i.e., contrast, brightness and/ or additional signal processing) have been completed. Evaluation of all relevant reflectors shall be performed in accordance with the applicable Code.
- 10.2 Evaluation Software - Evaluations may be performed as follows:
 - 10.2.1 Through the onboard Sonatest Prisma Phased Array Instrument running Prisma 4.5.1 software or later.
 - 10.2.3 Other software versions/revisions may be used provided they are approved and documented by the Level III and no essential variables are changed.

- 10.2.4 If a Soft Gain feature is utilized through any external software analysis program to aid in signal characterization it shall be noted on the report. Any accept or reject criteria will be applied with the Soft Gain value in the "zero" position.
- 10.3 Display Setting - Evaluations should be performed by using the A-B-S-and C views in conjunction with each other. Other views or combinations of views may be used at the discretion of the inspector.
- 10.4 Scan Quality - Scan quality shall be verified to meet the data drop-out requirements of paragraph 9.13 above. Rescanning shall be performed on any weld where the collected data appears suspect.
- 10.5 Indication Classification - All indications exceeding 20% of primary reference level shall be evaluated to the extent necessary that they can be evaluated to the requirements of the referencing code section.
- 10.5.1 Relevant Indications - All indications produced by reflectors within the volume to be examined, regardless of amplitude, that cannot be clearly attributed to the geometry of the weld configuration shall be considered as relevant indications.
- 10.5.2 Geometric or Metallurgical Indications - All indications produced by reflectors within the volume to be examined that can be attributed to the geometry of the weld configuration shall be considered as geometric or metallurgical indications and not relevant to the acceptance criteria. The identity, maximum amplitude, location, and extent of reflector causing a geometric indication shall be recorded.
- 10.5.2.1 The following steps shall be taken to classify an indication geometric:
- A. Interpret the area containing the reflector in accordance with the Flaw Indications or the Geometric or Metallurgical Indications criteria, listed below in this section,
 - B. Plot and verify the reflector coordinates. Prepare a cross-section sketch showing the reflector position and surface discontinuities such as root, weld crown.
 - C. Review radiographs, fabrication or weld preparation drawings, as-built drawings, or any other means available to accurately identify the reflector.
- 10.6 Geometric or Metallurgical Indications - All suspected geometric or metallurgical indications shall be investigated and evaluated considering the following indication characteristics. These characteristics should not be considered as mandatory criteria for classifying indications but are listed as significant points of interest for the examiner to consider during evaluation of suspect areas.
- 10.6.1 The indication appears at or near the centerline of the weld or other documented geometrical condition (i.e., counter bore) and can be seen continuously or intermittently along the length of the weld at consistent amplitude and sweep positions. This characteristic can be supported by obtaining localized thickness and surface contour

- recordings at the location of the indication(s) and by using the digital weld overlay feature.
- 10.6.2 The indication provides additional responses, which occur from the same scan position, but at different sweep positions (multiples) along the length of the weld. This may be a sign of mode- converted shear-wave signals from counter bore or similar geometric reflectors. This characteristic may require an increase in time base size to observe these responses.
 - 10.6.3 The indication can be seen across the entire length of the scan, either continuously or intermittently, at consistent amplitude and sweep positions. This characteristic can be supported by scanning along the indication length laterally.
 - 10.6.4 When examining with a higher angle search unit, the amplitude response is lower or not detected. This characteristic should consider localized thickness and contour information to ensure that the search unit angles provide comparable examination volume coverage and sound penetration. This characteristic can additionally be supported with an adequate reference reflector (Inside surface notch or equivalent).
 - 10.6.5 The indication provides minimal echo-dynamic travel (walk). This characteristic can be supported by observing other areas along the length of sample and with an adequate reference reflector (Inside surface notch or equivalent).
 - 10.6.6 The indication provides a rapid and consistent drop in signal amplitude when the beam is skewed away from normal in either direction.
 - 10.6.7 The indication provides a clean, single signal response with minimal to no signal faceting. No discernible tip signals are observable. This characteristic can be supported by optimizing the signal presentation on an adequate reference reflector (Inside surface notch or equivalent).
 - 10.6.8 The signal responses are consistent from each side of the weld for axial scans, or from each direction, clockwise (CW) or counterclockwise (CCW) for circumferential scans.
- 10.7 Flaw Indications - All suspected flaw indications shall be investigated and evaluated considering the following indication characteristics. These characteristics should not be considered as mandatory criteria for classifying indications as flaws but are listed as significant points of interest for the examiner to consider during evaluation of suspect areas.
- 10.7.1 The indication has a good signal-to-noise ratio (e.g., SN 2:1) with defined start and end points. This characteristic can be supported by observing signal-to-noise ratio variation along the length of the component.
 - 10.7.2 The indication plots to a location susceptible to cracking. This characteristic can be supported by obtaining localized thickness and

- surface contour recordings at the location of the indication(s).
- 5.0.1 The indication can be detected with multiple search unit angles, and a higher angle provides comparable or greater signal response. This characteristic can be supported with an adequate reference reflector (Inside surface notch or equivalent).
 - 5.0.2 The indication provides substantial and unique echo-dynamic travel (walk). This characteristic can be supported by observing other areas along the length of sample and with an adequate reference reflector (Inside surface notch or equivalent).
 - 10.7.5 Several areas of unique or multiple amplitude peaks are observed throughout the indication length. This characteristic can be supported by observing other areas along the length of sample and by scanning along the indication length laterally.
 - 10.7.6 The indication maintains or provides an increase in signal amplitude when the beam is skewed away from normal. This characteristic can be supported by observing other areas along the length of sample.
 - 10.7.7 Inconsistent time base positions are observed throughout the indication length as the search unit is moved parallel along the length of the reflector. This characteristic can be supported by scanning along the indication length laterally.
 - 10.7.8 The indication shows evidence of flaw tip signals, which can be sized using the real time cursors.
 - 10.7.9 Circumferential indications provide axial components while performing tangential scans.
 - 10.7.10 For circumferential flaws, the indication(s) can be confirmed from the opposite side of the weld. This characteristic may require a reduced search unit frequency or use of RL search unit in order to obtain adequate response.
 - 10.7.11 For axial flaws, the indication(s) can be confirmed from the opposite direction. This characteristic is dependent upon flaw orientation and may not always be available.
 - 10.7.12 The indication is in close proximity to, or initiates from, a geometrical reflector and distinct signal separation and amplitude fluctuation can be observed. This characteristic may require an increase in signal resolution capability to make this evaluation. Examples include reducing screen size and slower scan speeds.
 - 10.7.13 For components where access is limited to a single side of the component, the following additional information shall be considered:
 - 10.7.14 Because of the uncertainties associated with the flaw orientation and the actual thickness of the component on the inaccessible side of the weld, an accurate inside surface connection on the far side of the weld may be unobtainable.
- 10.8 Flaw Sizing - Flaws shall be sized in accordance with the applicable procedure demonstration to size similar flaws at similar material depths.

Suggested sizing methods are as follows:

10.8.1 Length Sizing - for unsaturated signals, the indication length shall be determined by using the 6dB drop method. Irregular flaws shall be sized using a 6dB drop from each end of the flaw.

10.8.1.1 For saturated signals in which the length criteria are suspect to determine pass/fail, the indications shall be rescanned at lower gain levels to eliminate saturation. Saturated indications which are grossly long or noted geometrical conditions may be measured using the peak-to-peak method where the indication drops below reference level screen height on each end.

10.8.2 Height Sizing - Through wall sizing of indications shall be done with the Tip Diffraction technique when diffracted signals are clearly evident in the data.

10.8.2.1 For unsaturated signals not exhibiting tip signals, the indication height shall be determined by using the peak-to-peak method where the indication drops 3dB (30% FSH). For saturated signals in which the height criteria are suspect to determine pass/fail, the indications shall be rescanned at lower gain levels to eliminate saturation.

10.8.3 Alternative Sizing Method - Alternatively, a flaw maybe sized by a supplemental manual technique so long as it has been qualified by the demonstration noted above.

11.0 ACCEPTANCE CRITERIA

11.1 Welds shall be evaluated in accordance with paragraph 10.0 and the applicable Code Attachment to this procedure. Unless otherwise stated in project requirements, the following acceptance criteria type shall be utilized:

11.1.1 ASME VIII, Workmanship Acceptance Criteria (Attachment 6) for MPAUT Examinations of Category "D" Nozzle Welds.

11.1.2 ASME VIII, Fracture Mechanics Acceptance Criteria (Attachment 7) Encoded PAUT Examinations of Butt Welds.

11.1.3 B31.3 - Workmanship Acceptance Criteria (Attachment 8)

11.1.4 B31.3 - Fracture Mechanics Acceptance Criteria (Attachment 9)

11.1.5 B31.1 - Workmanship Acceptance Criteria (Attachment 10)

11.1.6 B31.1 - Fracture Mechanics Acceptance Criteria (Attachment 11)

11.1.7 API 650 Welded Tanks for Oil Storage (Attachment 12)

11.1.8 API 1104 Welding of Pipelines and Related Facilities (Attachment 13)

12.0 EXAMINATION REPORTING CRITERIA

12.1 A Phased Array Examination Report shall be completed by the Level II or III interpreter upon completion of the review. The report may be produced using the equipment software, evaluation software, or handwritten. The report shall contain the following minimum information:

- 12.2 Non-Rejectable Indications - All reflectors having responses that exceed 50% of the reference level shall be reported to include the information detailed in 12.3 or 12.4 below as applicable.
- 12.3 Rejectable Indications - shall be recorded. For workmanship acceptance standards, the type of indication (i.e., crack, lack of fusion, slag, etc.), location, amplitude, and extent (i.e., length) shall be recorded.
 - 12.3.1 For fracture mechanics criteria, the indication height and length, location, and amplitude shall be recorded.
- 12.4 Geometrical Indications - At minimum, the maximum amplitude and location shall be recorded for reportable geometric conditions.
 - 12.4.1 For example: internal attachment, 200% TCG maximum amplitude, 1" above weld centerline, on the inside surface from 90° to 95°.
- 12.5 Report Content - For each examination, the following information, at minimum, shall be recorded on the report form:
 - 12.5.1 Calibration sheet identification.
 - 12.5.2 Names and certification levels of examination personnel.
 - 12.5.3 Examination procedure number and revision.
 - 12.5.4 Examination method, technique
 - 12.5.5 Basic calibration block identification and reference blocks.
 - 12.5.6 Ultrasonic instrument serial number, manufacturer, and model identification and essential instrument settings
 - 12.5.7 Search unit beam angle and mode of wave propagation in the material.
 - 12.5.8 Search unit manufacturer, model, and manufacturer's serial number.
 - 12.5.9 Search unit nominal frequency, size, shape, and number of elements.
 - 12.5.10 Search unit element size number. and pitch and gap dimensions.
 - 12.5.11 Special search units, wedges, shoe type, or saddle's identification, if used.
 - 12.5.12 Computerized program identification and revision when used.
 - 12.5.13 Search unit cable(s) used, type and length.
 - 12.5.14 Dates of initial calibration and subsequent calibration checks.
 - 12.5.15 Calibration data [including reference reflector(s), indication amplitude(s), and distance reading(s).
 - 12.5.16 Instrument reference level gain, damping and reject setting(s), if used.
 - 12.5.17 Couplant type and batch number.
 - 12.5.18 Examination sensitivity.
 - 12.5.19 Focal law parameters, including, as applicable, angle or angular

- range element numbers used angular or element incremental change. and start and stop element numbers or start element number.
- 12.5.20 Wedge natural refracted angle.
 - 12.5.21 Instrument settings to include, as a minimum, excitation pulse type, duration and voltage settings, digitization rate (e.g., nominal rate as affected by compression and points quantity), rectification, pulse repetition rate, range start and stop, band pass filters, smoothing, focal type, and length.
 - 12.5.22 Scan plan and scan plan variables.
- 12.6 Examination data shall be recorded on an Ultrasonic Examination Data Sheet and as a minimum, shall include the following:
- 12.6.1 Data sheet identification and date of examination.
 - 12.6.2 Names and certification levels of examination personnel.
 - 12.6.3 Calibration sheet identification.
 - 12.6.4 Identification of the weld, part, or component examined including weld number, serial number, or another identifier.
 - 12.6.5 Identification and location of the weld and volume scanned.
 - 12.6.6 Surface from which the examination is conducted, including surface condition.
 - 12.6.7 Examination results including limitations of the volume scanned.
 - 12.6.8 Map or record of rejectable indications detected, or areas cleared.
 - 12.6.9 Areas of restricted access or inaccessible welds
 - 12.6.10 Indication classification of all recordable reflectors.
 - 12.6.11 Rejectable indications shall be recorded.
- 12.7 Items 12.6.1 thru 12.6.11 may be provided in a separate calibration record provided the calibration record identification is included in the examination report.
- 12.8 The examination report should also include screen shots and notations for reported indications found during the evaluation.
- 12.9 Final Data Package
- 12.9.1 Disposition of Data -The original scanning data, unprocessed, shall be saved and stored electronically (e.g., magnetic, optical, flash memory, etc.) and included in the data record. All data shall be submitted upon the customer's request. Examination data may be transferred by any electronic means as agreed upon with the customer.
 - 12.9.2 Retention - A copy of all examination data shall be kept on file until the conclusion of each project or other lengths of time as agreed upon or stipulated in the contract documents.

12.9.3 If external software is used (i.e., Omni PC), the converted files along with standard configurations shall be made available to the client upon request.

13.0 ATTACHMENTS

Attachment 1	MPAUT Application Requirements.
Attachment 2	Instruction Sheet for Equipment Qualification.
Attachment 3	Instruction Sheet for Verifying Element Operability.
Attachment 4	Scan Plan Template.
Attachment 5	Ultrasonic Examination (UT) Report.
Attachment 6	ASME VIII – Workmanship Acceptance Criteria for Nozzles.
Attachment 7	ASME VIII – Fracture Mech Based Acceptance Criteria.
Attachment 8	B31.3 – Workmanship Acceptance Criteria.
Attachment 9	B31.3 – Fracture Mechanics Acceptance Criteria.
Attachment 10	B31.1 – Workmanship Acceptance Criteria.
Attachment 11	B31.1 – Fracture Mechanics Acceptance Criteria.
Attachment 12	API 650 – Workmanship Acceptance Criteria
Attachment 13	API 1104 – Workmanship Acceptance Criteria

Attachment 1 MANUAL PAUT APPLICATION (MPAUT)

1.0 SCOPE

- 1.1 This Attachment covers the use of MPAUT using to meet the requirements of ASME Section V - Article 4 and Mandatory Appendix IV.
- 1.2 Procedure Qualification is not required unless the essential variables listed in TABLE IV-421 of the main body of the procedure or the additional requirements detailed within this Annex are not adhered to.

2.0 MPAUT SCANNING REQUIREMENTS

- 2.1 All requirements of the main body of this procedure shall apply except as modified below:
- 2.2 Equipment Provisions - Equipment requirements of Section 6.0 of the base procedure shall apply except as follows:
 - 2.2.1 Phased Array Instruments- may be of the manual type capable of generating Sectorial and/or E- Scans and capable of displaying a minimum of A-Scan and S-Scan imaging views.
 - 2.2.2 Scanners - A scanner is not applicable.
- 2.3 Scan Plans - Scan Plans are required for MPAUT applications.
- 2.4 Focal Law Configuration - Focal laws shall be configured as detailed in Section 7.4 in the base procedure. Primary weld scanning shall be performed with Sectorial Scans between the angle of 40 and 70 degrees. Additional scan types or wider-angle ranges may be used to aide in flaw evaluation as necessary. Since manual scanning is performed, the scan requirements of Section 7.5 of the base procedure do not apply however they should be considered for detection principles during manual scanning.
- 2.5 Calibration - The calibration and general setup requirements of Section 8.0 in the base procedure, shall apply except as follows:
 - 2.5.1 Encoder calibration is not applicable.
- 2.6 Weld Inspection Procedure - The requirements of Section 9.0 in the base procedure, shall apply except as modified below.
 - 2.6.1 Encoded Line Scanning – Section 9.8 in the base procedure is not applicable.
 - 2.6.2 Perpendicular Flaw Detection - Scanning shall be performed by manual rastering in the form of line scans with the direction of ultrasound perpendicular to the weld axis and probe movement parallel to the weld axis. The S-Scan view shall be monitored during the scanning process. Subsequent scans shall be made by manual indexing with a minimum of 50% probe overlap between each scan until the examination coverage requirements of Section 7.3, in the base procedure, are met. Slight oscillation of the search unit is permitted during manual scanning provided improved coverage is obtained.
 - 2.6.3 Transverse Flaw Detection - Transverse flaws detection shall be as described in Section 9.9, in the base procedure, except manual scanning shall be performed.

- 2.6.4 Scanning Gain on Base Material - A minimum of 6 dB' s of additional gain over reference level shall be applied for manual scanning when scanning on the base metal.
- 2.6.5 Scanning Gain on top of the weld - A minimum of 12 dB' s of additional gain over primary reference level shall be applied for manual scanning when scanning on the top of the weld for the detection of transverse reflectors.
- 2.6.6 Scanning Speed - The maximum scan speed shall not exceed the data acquisition rate or 2.0 inches per second, whichever is less.
- 2.6.7 Data Requirements - Data requirements of sections 9.8, 9.11 and 9.14, in the base procedure, are not applicable.
- 2.6.8 Display Requirements - An A and S-Scan imaging view shall be used during all MPAUT scanning applications.

3.0 EVALUATION AND ACCEPTANCE REQUIREMENTS

- 3.1 All requirements of the main body of this procedure shall apply except as modified below:
- 3.2 Evaluation - Evaluation, including flaw sizing, shall be performed at each weldment using the A and S scan displays and by bringing indications down to primary reference level dB. All other requirements of Section 10.0, in the base procedure, pertaining to evaluation and indication discrimination shall apply.
- 3.3 Acceptance Criteria -All indications evaluated to be from relevant discontinuities shall be assessed using the applicable Appendix. All evaluation for acceptance shall be performed at primary reference level dB.

4.0 REPORTING REQUIREMENTS

- 4.1 Content: All reporting requirements of Section 12.0, in the base procedure, shall apply. If requested by the customer, images may be inserted to document flaw indications as specified.
- 4.2 Data Package - The requirements of Section 12.9, in the base procedure are not applicable.

Attachment 2 EQUIPMENT QUALIFICATION INSTRUCTIONS

1.0 General Requirements

- 1.1 Linearity verifications shall be conducted every 12 months & recorded on a form similar to that shown in Table IV-421.
 - 1.1.1 The phased array instrument shall be configured to display an A-scan presentation.
 - The time-base of the A-scan shall be adjusted to a suitable range to display the pulse-echo signals selected for the linearity verification to be performed. A standard IIW or other linearity block similar to that described in ASTM E 317 shall selected to provide signals to assess linearity aspects of the instrument.
 - Pulser parameters shall be selected for the frequency and

bandpass filter to optimize the response from the pulse-echo (single element) probe used for the linearity verifications.

- The receiver gain shall be set to display non-saturating signals of interest for display height and amplitude control linearity assessments.

4.1 Display Height Linearity Verification Procedure

1.2.1 With the phased array instrument connected to a probe (shear or longitudinal) and coupled to any block that will produce two signals, adjust the probe such that the amplitude of the two signals are at 80% and 40% of the display screen height.

- Increase the gain using the receiver gain adjustment to obtain 100% of full screen height of the larger response. The height of the lower response is recorded at this gain setting as a percentage of full screen height.
- Reduce the height of the higher response in 10% steps to 10% of full screen height and record the height of the second response for each step.
- Return the larger signal to 80% to ensure that the smaller signal has not drifted from its original 40% level due to coupling variation. Repeat the test if variation of the second signal is greater than 41% or less than 39% full screen height.
- For an acceptable tolerance, the responses from the two reflectors should bear a 2 to 1 relationship to within $\pm 3\%$ of full screen height throughout the range 10% to 100% (99% if 100% is saturation) of full screen height.

1.3 Amplitude Control Linearity Verification Procedure

1.3.1 Each of the pulser-receiver components shall be checked to determine the linearity of the instrument amplification capabilities.

- Select a flat (normal incidence) linear array phased array probe having at least as many elements as the phased array ultrasonic instrument has pulsers.
- Using this probe, configure the phased-array ultrasonic instrument to have an E-scan at 0° . Each focal law will consist of one element and the scan will start at element number 1 and end at the element number that corresponds to the number of pulsers in the phased-array instrument.
- Couple the probe to a suitable surface to obtain a pulse-echo response from each focal law. The backwall echo from the 1-in thickness of the IIW block or similar block provides a suitable target option. Alternatively, immersion testing can be used.
- Select Channel 1 of the pulser-receivers of the phased-array instrument. Using the A-scan display, monitor the response from the selected target. Adjust the gain to bring the signal to 40% screen height.

- Add gain to the receiver in the increments of 1 dB, then 2 dB, then 4 dB and then 6 dB. Remove the gain added after each increment to ensure that the signal has returned to 40% display height. Record the actual height of the signal as a percentage of the display height.
 - Adjust the signal to 100% display height, remove 6 dB gain and record the actual height of the signal as a percentage of the display height.
 - Signal amplitudes shall fall within a range of $\pm 3\%$ of the display height required in the allowed height range of Table IV-421.
- Repeat the sequence from 1.3.1.1 to 1.3.1.7 for all other pulser-receiver channels.
 - For instruments having 10- or 12-bit amplitude digitization and configured to read amplitudes in a gated region to amplitudes greater than can be seen on the display, a larger range of checkpoints can be used. For these instruments the gated output instead of the A-scan display would be verified for linearity.
- 1.1 Time-Base Linearity (Horizontal Linearity) Verification Procedure
- Configure the phased array instrument to display an A-scan presentation using a 10-inch range.
 - Select any longitudinal (compression) wave probe and configure the phased-array instrument to display a range suitable to obtain at least ten multiple back reflections from the 1-inch wall thickness of the IIW block.
 - Set the phased-array instrument analog-to-digital conversion rate to at least 80 MHz.
- 1.4.4 With the probe coupled to the block and the A-scan displaying 10 clearly defined multiples, use the display software to assess the interval between adjacent backwall signals.
- 1.4.5 Determine acoustic velocity of the test block by calibration (AS1M E494 may be used as a guide), enter the acoustic velocity in the display software, and configure the display to read out in distance (thickness).
- 1.4.6 Using the reference and measurement cursors, determine the interval between each multiple and record the interval of the first 10 multiples.
- 1.4.7 Each trace deflection shall be correct within 2% of the screen width.

Attachment 3 ELEMENT OPERABILITY CHECK**1.0 SCOPE**

- 1.1 This document provides instructions for verifying the element operability of a transducer. The objective is to check each individual element in a particular phased array probe, to ensure adequate operability.

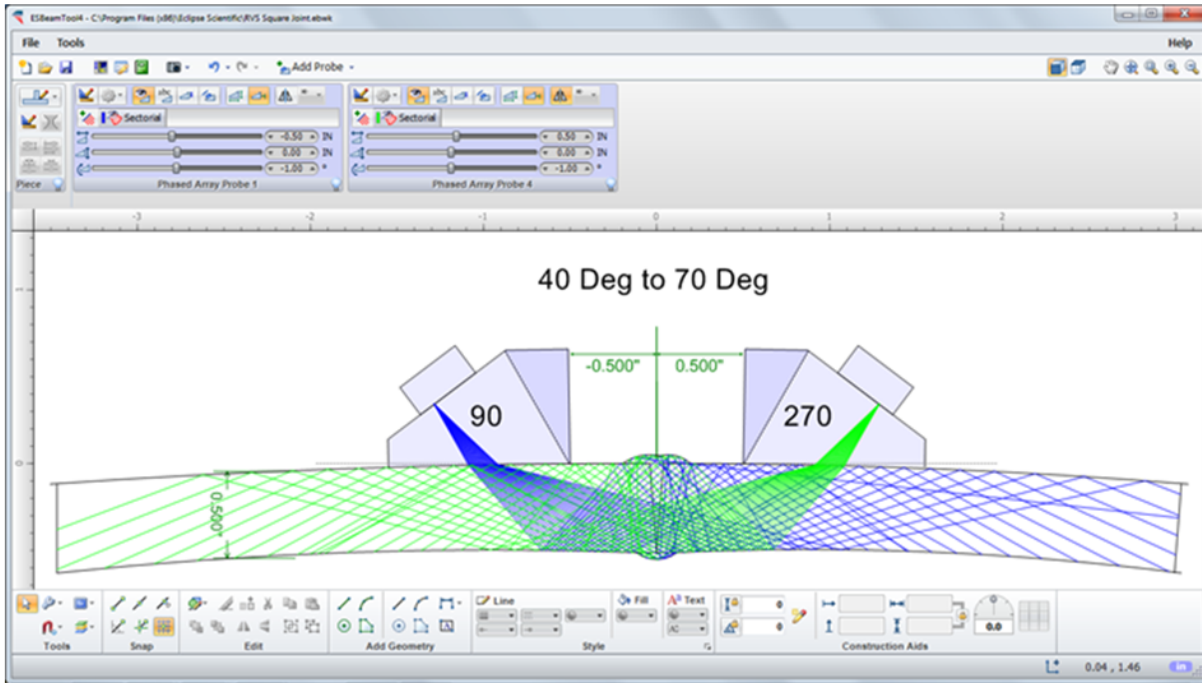
2.0 GENERAL REQUIREMENTS

- 2.1 Warm-up - Equipment shall be allowed to stabilize (warm up) for a minimum of 5 minutes prior to calibration.
- 2.2 All calibration shall be conducted with Suppression and Reject controls turned off at minimum settings.
- 2.3 Calibration Standard - any standard that has parallel front and back surfaces may be used for this verification. A longitudinal beam wedge or IIW type block are typical blocks implemented.

3.0 PROCEDURE

- 3.1 Focal Law - Configure the selected transducer for a Linear at 0° array with the wedge setting on contact. Fire 1 element at a time with the first element being set to 1 and the last element set to the maximum number of elements in the selected transducer. Focal depth is irrelevant.
- 3.2 Initial Set-Up -Affix the transducer to a calibration standard that has parallel front and back surfaces. Adjust the system Range to image the initial pulse and the first back reflection from the calibration standard.
- 3.3 Scroll through each angle to find the element that yields the highest response. Set this signal at 80% FSH.
- 3.4 Without changing the gain, scroll through all other elements of the transducer and note the amplitude response from each. The amplitude from each element should be approximately the same amplitude.
- 3.5 Any element that does not produce a signal is considered dead. There shall not be two dead elements adjacent to each other.

Attachment 4 SCAN PLAN TEMPLATE



Attachment 5 Ultrasonic Examination (UT) Report

Attachment 6 ASME Section I and Section VIII DIV. 1 and 2 – Pressure Vessels WORKMANSHIP BASED ACCEPTANCE CRITERIA

1.0 SCOPE

- 1.1 This Appendix covers the evaluation of welds, 250" thick and greater, to ASME Section VIII, Divisions 1 and 2, using the Workmanship Acceptance Criteria and MUT.

2.0 EVALUATION

- 2.1 Evaluations shall be performed in accordance with Section 10.0 of the base procedure.
- 2.2 Flaws shall be sized (height and length) in accordance with Section 10.8 of the base procedure.
- 2.3 Flaws shall be characterized by flaw type. (i.e.: lack of fusion, lack of penetration, cracks)

3.0 ACCEPTANCE CRITERIA

- 3.1 Welds that are shown by ultrasonic examination to have discontinuities which produce a response greater than 20% of the primary reference level shall be investigated to the extent that the operator can determine the shape, identity, and location of all such reflectors, and evaluate them in terms of the acceptance standards given below:
 - 3.2 Where discontinuities are interpreted to be cracks, lack of fusion or incomplete penetration, they are unacceptable, regardless of length.
 - 3.3 Other discontinuity types (i.e., slag/porosity) shall be deemed unacceptable if the amplitude exceeds the primary reference level, and lengths that exceed:
 - 3.3.1 1/4" for t less than 3/4".
 - 3.3.2 $t/3$ for t greater than or equal to 3/4" and less than or equal to 2-1/4".
 - 3.3.3 3/4" for t greater than 2-1/4".

" t " is the thickness of the weld excluding any allowable reinforcement. For a butt weld joining two members having different thicknesses at the weld, t is the thinner of these two thicknesses. If a full penetration weld includes a fillet weld, the thickness of the throat of the fillet shall be included in t .

4.0 REPORT OF EXAMINATION

- 4.1 Examination results shall be documented on report form meeting the requirements of Section 12.0 of the base procedure. All reflectors having responses that exceed 50% of the primary reference level shall be reported. The following minimum information shall be recorded for each reportable indication.
 - 4.1.1 Percent screen height as related to DAC Level.
 - 4.1.2 Discontinuity Type (i.e., lack of fusion, lack of penetration, crack, etc.)
 - 4.1.3 Discontinuity length.
 - 4.1.4 Depth below the scanning surface.

4.1.5 Approximate location along the weld length (X and Y measurement).

Attachment 7 ASME SECTION VIII DIVISION 1 AND 2 - PRESSURE VESSELS FRACTURE MECHANICS BASED ACCEPTANCE CRITERIA

1.0 SCOPE

- 1.1 This Appendix covers the evaluation of welds, 250" thick and greater, to ASME Section VIII, Divisions 1 and 2, using the Fracture Mechanics Based Acceptance Criteria and the Encoded Phased Array Technique.
- 1.2 A documented scan plan shall be written in accordance with section 7.0 of the base procedure and provided to the customer upon request.

2.0 EVALUATION

- 2.1 Data Analysis Criteria - Reflectors exceeding the limits in 2.1.1 below shall be investigated to determine whether the indication originates from a flaw or is a geometric indication in accordance with paragraph 2.2 below. When a reflector is determined to be a flaw, it shall be evaluated for acceptance in accordance with Section 3.
 - 2.1.1 Amplitude Based Techniques -the location, amplitude, and extent of all reflectors that produce a response greater than 20% of the primary reference level shall be investigated.
- 2.2 Geometric Evaluation - Indications that are determined to originate from the surface configurations (such as weld reinforcement or root geometry) or variations in metallurgical structure of materials (such as cladding to base metal interface) may be classified as geometric indication, and need not be characterized, sized, or compared to allowable flaw criteria as stipulated in 3.
 - 2.2.1 The steps to be taken to classify an indication as geometric shall be in accordance with Section 10.6, of the base procedure.:
 - A. **Alternatively, other NDE methods or techniques may be applied to classify an indication as geometric (e.g., alternative UT beam angles, radiography, ID and/or OD profiling).**
- 2.3 Flaw Sizing - Flaws shall be sized in accordance with the qualified procedure/scan plan.
 - 2.3.1 Dimensions of Flaws- The dimensions of flaws shall be determined by a rectangle that fully contains the area of the flaw. See Figures 7.11 thru 7.15.
 - A. The length (1) of the flaw shall be drawn parallel to the inside pressure retaining surface of the component.
 - B. The depth of the flaw shall be drawn normal to the inside pressure retaining surface and shall be denoted as "a" for surface flaw or "2a" for subsurface flaw.
 - C. Subsurface flaw(s) close to a surface shall be considered surface flaw(s) if the distance between the flaw and the nearest surface is equal to or less than one-half the flaw through-wall dimension, as shown in Figures 7.11 through 7.15.

3.0 ACCEPTANCE CRITERIA

3.1 Flaws shall be evaluated for acceptance using the applicable criteria of Tables 7.8, 7.9, or 7.10 and with the following additional requirements.

3.1.1 For surface connected flaws, the measured through-wall dimension, a , shall be compared to the value of a as determined from the applicable flaw acceptance criteria table.

3.1.2 For subsurface flaws, the measured through-wall dimension, $2a$, shall be compared to twice the value of a as determined from the applicable flaw acceptance criteria table.

3.1.3 Surface Flaws - Flaws identified as surface flaws during the UT examination may or may not be surface connected, as shown in Figures 7.11 through 7.15. Therefore, unless the UT data analysis confirms that the flaw is not surface connected, it shall be considered surface connected or a flaw open to the surface and is unacceptable unless surface examination is performed. If the flaw is surface connected, the requirements above still apply. However, in no case shall the flaw length, l , exceed the acceptance criteria in this Division. Acceptance surface examination techniques are as follows:

A. Magnetic Particle Examination in accordance with Appendix 6 of Section VIII – Division 1 or Appendix 9-1 of Section VIII - Division 2; as applicable, or

B. Liquid Penetrant Examination in accordance with Appendix 8 of Section VIII – Division 1; Appendix 9-2 of Section VIII - Division 2; as applicable.

3.1.4 Multiple Flaws

A. Discontinuous flaw shall be considered a singular planar flaw if the distance between adjacent flaws is equal to or less than S as shown in Figure 7.14.

B. Discontinuous flaws that are oriented primarily in parallel planes shall be considered a singular planar flaw if the distance between the adjacent planes is equal to or less than $\frac{1}{2}$ ". (Refer to Figure 7.15).

C. Discontinuous flaws that are coplanar and nonaligned in the through-wall thickness direction of the component shall be considered a singular planar flaw if the distance between adjacent flaws is equal to or less than S as shown in Figure 7.16.

D. Discontinuous flaws that are coplanar in the through-wall direction within two parallel planes $\frac{1}{2}$ " apart (i.e., normal to the pressure retaining surface of the component) are unacceptable if the additive flaw depth dimension of the flaws exceed those shown in Figure 7.17.

E. Subsurface Flaws - Flaw length (1) shall not exceed $4t$.

Attachment 8 ASME B31.3 – Process Piping WORKMANSHIP BASED ACCEPTANCE CRITERIA

1.0 SCOPE

- 1.1 This Attachment covers the evaluation of welds, 250" thick and greater, to B31.3 Piping welds, using the Workmanship Acceptance Criteria and MUT.

2.0 EVALUATION

- 2.1 Evaluations shall be performed in accordance with Section 10.0 of the base procedure.
- 2.1 Discontinuities shall be sized (height and length) in accordance with Section 10.8 of the base procedure.

3.0 ACCEPTANCE CRITERIA

- 3.1 Welds that are shown by ultrasonic examination to have discontinuities which produce a response greater than 20% of the primary reference level shall be investigated to the extent that the operator can determine the shape, identity, and location of all such reflectors, and evaluate them in terms of the acceptance standards given below:
 - 3.2 Acceptance criteria shall be as described as specified in section 3.3 below.
 - 3.3 A discontinuity is unacceptable if the amplitude of the indication exceeds the reference level, and its length exceeds:
 - 3.3.1 1/4 in. for T_w 3/4 in.
 - 3.3.2 $T_w/3$ for 3/4 in. $< T_w$ 2-1/4 in.
 - 3.3.3 3/4 in. for $T_w > 2-1/4$ in.

T_w is the nominal wall thickness of the thinner of two components joined by a butt weld.

4.0 REPORT OF EXAMINATION

- 4.1 Examination results shall be documented on report form meeting the requirements of Section 12.0 of the base procedure.

Attachment 9 ASME B31.3 – Process Piping FRACTURE MECHANICS BASED ACCEPTANCE CRITERIA

1.0 SCOPE

- 1.1 This Appendix covers the evaluation of welds, 250" thick and greater, to B31.3 Piping Welds, using the Fracture Mechanics Acceptance Criteria and the Manual Phased Array.
- 1.2 A documented scan plan shall be written in accordance with Section 7.0 of the base procedure and provided to the Owner/User upon request.

2.0 EVALUATION

- 2.1 Evaluations shall be performed in accordance with Section 10.0 of the base procedure.
- 2.2 Flaws shall be sized (height and length) in accordance with the procedure qualification record and documented scan plan and Section 10.8 of the base procedure.
- 2.3 FLAW EVALUATION
- 2.3.1 Dimensions. The dimensions of the flaw(s) shall be determined by the rectangle that fully contains the area of the flaw(s). Refer to Figure R307.
- A. The length, l_F , of the flaw shall be drawn parallel to the inside pressure-retaining surface of the component.
- B. The height, h_F , of the flaw shall be drawn normal to the inside pressure-retaining surface of the component.
- C. The flaw shall be characterized as a surface or subsurface flaw, as shown in Figure R307-1.
- D. A subsurface flaw shall be considered as a surface flaw if the separation (S_F in Figure R307-1) of the flaw from the nearest surface of the component is equal to or less than half the through-wall dimension [h_F in Figure R307-1, illustration (b)] of the subsurface flaw.
- 2.3.2 Multiple Flaws
- A. Discontinuous flaws that are oriented primarily in parallel planes shall be considered to lie in a single plane if the distance between the adjacent planes is equal to or less than 13 mm (0.50 in.) or $0.5T_w$, whichever is

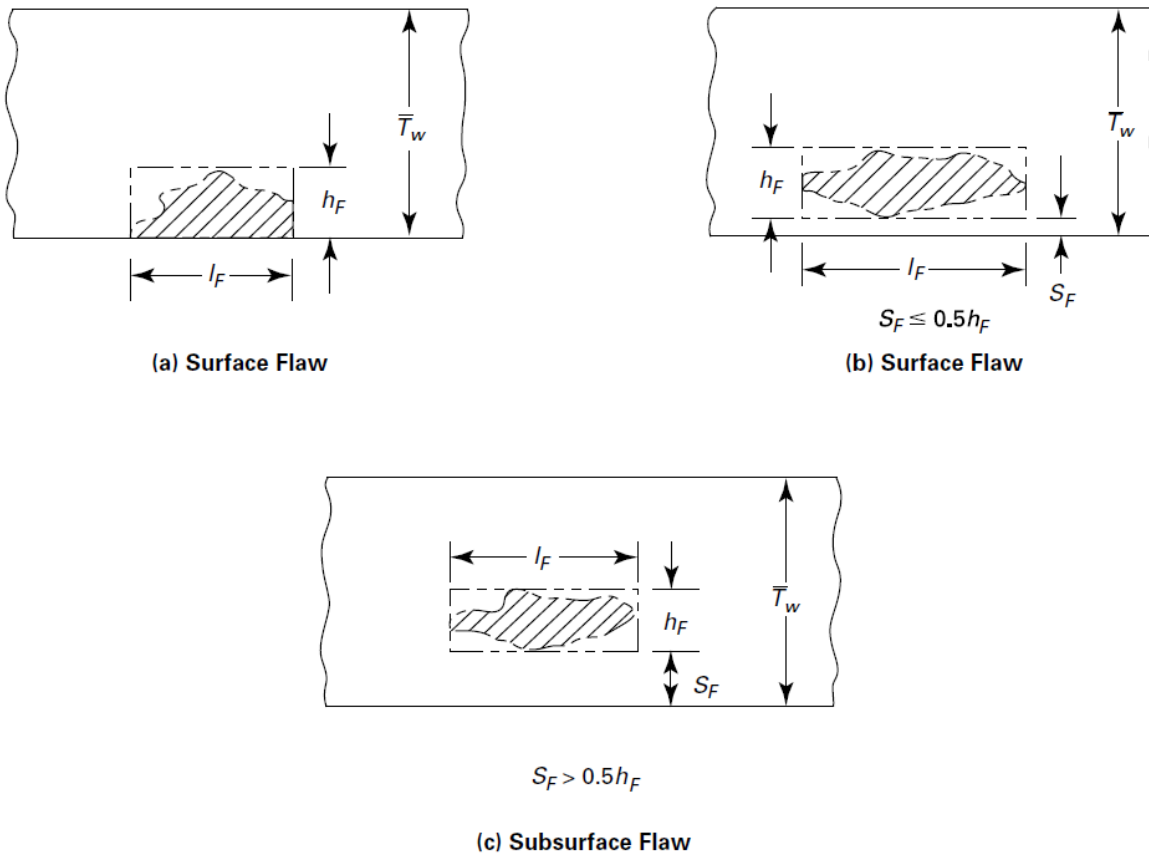
less.

- B. If the space between two flaws aligned along the axis of weld is less than the height of the flaw of greater height, the two flaws shall be considered a single flaw.
- C. If the space between two flaws aligned in the through-thickness dimension is less than the height of the flaw of greater height, the two flaws shall be considered a single flaw.

3.0 ACCEPTANCE CRITERIA

- 3.1 Flaws shall be evaluated using the applicable criteria of Table R308-1 or Table R308-2. Regardless of flaw height or aspect ratio, flaw length shall not exceed $4T_w$.

**Figure R307-1
Surface and Subsurface Flaws**



**Table R308-1
Acceptance Criteria for Surface Flaws**

Aspect Ratio, h_F/l_F	Maximum h_F/\bar{T}_w for Nominal Weld Thickness	
	25 mm to 65 mm (1.0 in. to 2.5 in.)	100 mm to 300 mm (3.9 in. to 11.8 in.)
	0.00	0.031
0.05	0.033	0.020
0.10	0.036	0.022
0.15	0.041	0.025
0.20	0.047	0.028
0.25	0.055	0.033
0.30	0.064	0.038
0.35	0.074	0.044
0.40	0.083	0.050
0.45	0.085	0.051
0.50	0.087	0.052

GENERAL NOTES:

- (a) Aspect ratio (h_F/l_F) used may be determined by rounding the calculated h_F/l_F down to the nearest 0.05 increment value within the column, or by linear interpolation.
- (b) For intermediate thickness \bar{T}_w [thicknesses greater than 65 mm (2.5 in.) and less than 100 mm (3.9 in.)], linear interpolation is permitted to obtain h_F/\bar{T}_w values. Otherwise, the lower values shall be used.

**Table R308-2
Acceptance Criteria for Subsurface Flaws**

Aspect Ratio, h_F/l_F	Maximum h_F/\bar{T}_w for Nominal Weld Thickness	
	25 mm to 65 mm (1.0 in. to 2.5 in.)	100 mm to 300 mm (3.9 in. to 11.8 in.)
	0.00	0.068
0.10	0.076	0.044
0.20	0.086	0.050
0.30	0.108	0.058
0.40	0.132	0.066
0.50	0.156	0.080
0.60	0.180	0.094
0.70	0.206	0.108
0.80	0.232	0.122
0.90	0.258	0.138
1.00	0.286	0.152

GENERAL NOTES:

- (a) Aspect ratio (h_F/l_F) used may be determined by rounding the calculated h_F/l_F down to the nearest 0.10 increment value within the column, or by linear interpolation.
- (b) For intermediate thickness \bar{T}_w [thicknesses greater than 65 mm (2.5 in.) and less than 100 mm (3.9 in.)], linear interpolation is permitted to obtain h_F/\bar{T}_w values. Otherwise, the lower values shall be used.

**Attachment 10 ASME B31.1 – Power Piping
WORKMANSHIP BASED ACCEPTANCE CRITERIA**

1.0 SCOPE

- 1.1 This Appendix covers the evaluation of welds, 250" thick and greater, to B31.1 Piping welds, using the Workmanship Acceptance Criteria and the Manual Phased Array.
- 1.2 A documented scan plan shall be written in accordance with Section 7.0 of the base procedure and provided to the Owner/User upon request.

2.0 EVALUATION

- 2.1 Evaluations shall be performed in accordance with Section 10.0 of the base procedure.

- 2.2 Discontinuities shall be sized (height and length) in accordance with the procedure qualification record and documented scan plan and Section 10.8 of the base procedure.

3.0 ACCEPTANCE CRITERIA

- 3.1 Welds that are shown by ultrasonic examination to have discontinuities which produce a response greater than 20% of the primary reference level shall be investigated to the extent that the operator can determine the shape, identity, and location of all such reflectors, and evaluate them in terms of the acceptance standards given below:
 - 3.2 Discontinuities evaluated as being cracks, lack of fusion or incomplete penetration, are unacceptable, regardless of length.
 - 3.3 Other discontinuity are unacceptable if the indication exceeds the primary reference level, and lengths exceeds the following:
 - 3.3.1 $\frac{1}{4}$ " for t up to $\frac{3}{4}$ "
 - 3.3.2 $\frac{1}{3}t$ for t over $\frac{3}{4}$ " to 2-1/4"
 - 3.3.3 $\frac{3}{4}$ " for over 2-1/4"

Where "t" is the thickness of the weld being examined. If the weld joins two members having different thicknesses at the weld, "t" is the thinner of these two thicknesses.

4.0 REPORT OF EXAMINATION

- 4.1 Examination results shall be documented on report form meeting the requirements of Section 12.0 of the base procedure.

Attachment 11 ASME B31.1 – Power Piping FRACTURE MECHANICS BASED ACCEPTANCE CRITERIA

1.0 SCOPE

- 1.1 This Appendix covers the evaluation of welds, 250" thick and greater, to B31.1 Piping Welds, using the Fracture Mechanics Acceptance Criteria and the Manual Phased Array.
- 1.2 A documented scan plan shall be written in accordance with Section 7.0 of the base procedure and provided to the Owner/User upon request.

2.0 EVALUATION

- 2.1 Evaluations shall be performed in accordance with Section 10.0 of the base procedure.
- 2.2 Flaws shall be sized (height and length) in accordance with the procedure qualification record and documented scan plan and Section 10.8 of the base procedure.

2.3 FLAW EVALUATION

2.3.1 Dimensions. The dimensions of the discontinuity shall be determined by the rectangle that fully contains the area of the flaw(s). Refer to Figure O-8.1.

- A. The length, l , of the discontinuity shall be drawn parallel to the inside pressure-retaining surface of the component.
- B. The height, h , of the discontinuity shall be drawn normal to the inside pressure-retaining surface of the component.
- C. The discontinuity shall be characterized as a surface or subsurface flaw, as shown in Figure O-8.1.
- D. A subsurface discontinuity shall be considered as a surface flaw if the separation (S in Figure O-8.1) of the indication from the nearest surface of the component is equal to or less than half the through-wall dimension [h in Figure O-8.1, illustration (b)] of the subsurface indication.

2.3.2 Multiple Flaws

- A. Discontinuous indications that are oriented primarily in parallel planes shall be considered to lie in a single plane if the distance between the adjacent planes is equal to or less than 0.50 in. (13 mm) or $0.5t$, whichever is less.
- B. If the space between two indications aligned along the axis of weld is less than the height of the indication of greater height, the two discontinuities shall be considered a single discontinuity.
- C. If the space between two indications aligned in the through-thickness dimension is less than the height of the indication of greater height, the two indications shall be considered a single flaw.

3.0 ACCEPTANCE CRITERIA

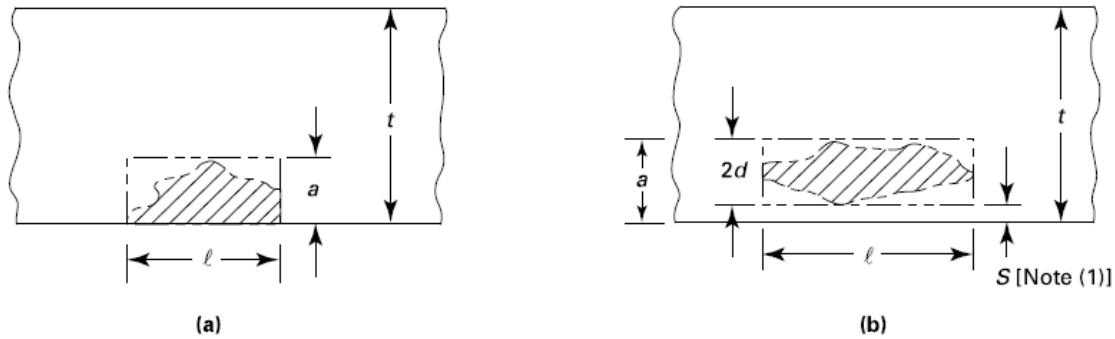
- 3.1 For amplitude-based techniques, the location, amplitude, and extent of all reflectors that produce a response greater than 20% of the reference level

shall be evaluated.

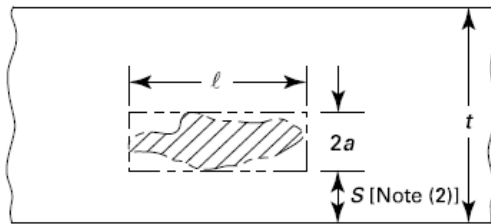
3.1.1 For non-amplitude-based techniques, the location and extent of all images that have an indicated length greater than 0.16 in. shall be investigated.

3.2 Discontinuities shall be evaluated using the applicable criteria of Table O-9-1 through O-9-3. Regardless of discontinuity height or aspect ratio, discontinuity length shall not exceed $4t$.

Figure O-8-1 Surface and Subsurface Indications



Surface Indications



(c) Subsurface Indications

NOTES:

(1) $S \leq 0.5h$.

(2) $S > 0.5h$.

Table O-9-1 Discontinuity Acceptance Criteria for Weld Thickness Under 1.0 in. (25 mm)

Discontinuity	h/t	ℓ
Surface	0.100 or less	0.25 in. (6.4 mm) or less
Subsurface	0.286 or less	0.25 in. (6.4 mm) or less

GENERAL NOTES:

- (a) t is the thickness of the weld excluding any allowable reinforcement. For a butt joint joining two members having different thicknesses at the joint, t is the thinner of the two thicknesses joined. If a full penetration weld includes a fillet weld, the effective throat dimension of the fillet weld shall be included in t .
- (b) A discontinuity is considered rejectable if its dimensions exceed the h/t value or the ℓ value in this Table.

Table O-9-2 Surface Discontinuity Acceptance Criteria for Weld Thickness 1.0 in. (25 mm) and Over

Aspect Ratio, h/ℓ	Maximum h/t for Weld Thickness		
	1.0 in. to 2.5 in. (25 mm to 64 mm)	Over 2.5 in. to Under 3.9 in. (64 mm to 100 mm)	3.9 in. to 11.8 in. (100 mm to 300 mm)
0.00	0.031	See Note (1)	0.019
0.05	0.033	See Note (1)	0.020
0.10	0.036	See Note (1)	0.022
0.15	0.041	See Note (1)	0.025
0.20	0.047	See Note (1)	0.028
0.25	0.055	See Note (1)	0.033
0.30	0.064	See Note (1)	0.038
0.35	0.074	See Note (1)	0.044
0.40	0.083	See Note (1)	0.050
0.45	0.085	See Note (1)	0.051
0.50	0.087	See Note (1)	0.052

GENERAL NOTES:

- (a) t is the thickness of the weld excluding any allowable reinforcement. For a butt joint joining two members having different thicknesses at the joint, t is the thinner of the two thicknesses joined. If a full penetration weld includes a fillet weld, the effective throat dimension of the fillet weld shall be included in t .
- (b) The aspect ratio (h/ℓ) used may be determined by rounding the calculated h/ℓ down to the nearest 0.05 increment value within the column, or by linear interpolation.
- (c) Regardless of discontinuity height or aspect ratio, discontinuity length shall not exceed $4t$.

NOTE: (1) For intermediate thicknesses, t [weld thicknesses between 2.5 in. and 3.9 in. (64 mm and 100 mm)], linear interpolation is required to obtain h/t values.

Table O-9-3 Subsurface Discontinuity Acceptance Criteria for Weld Thickness 1.0 in. (25 mm) and Over

Aspect Ratio, h/ℓ	Maximum h/t for Weld Thickness		
	1.0 in. to 2.5 in. (25 mm to 64 mm)	Over 2.5 in. to Under 3.9 in. (64 mm to 100 mm)	3.9 in. to 11.8 in. (100 mm to 300 mm)
0.00	0.068	See Note (1)	0.040
0.10	0.076	See Note (1)	0.044
0.20	0.086	See Note (1)	0.050
0.30	0.098	See Note (1)	0.058
0.40	0.114	See Note (1)	0.066
0.50	0.132	See Note (1)	0.076
0.60	0.156	See Note (1)	0.088
0.70	0.180	See Note (1)	0.102
0.80	0.210	See Note (1)	0.116
0.90	0.246	See Note (1)	0.134
1.00	0.286	See Note (1)	0.152

GENERAL NOTES:

- (a) t is the thickness of the weld excluding any allowable reinforcement. For a butt joint joining two members having different thicknesses at the joint, t is the thinner of the two thicknesses joined. If a full penetration weld includes a fillet weld, the effective throat dimension of the fillet weld shall be included in t .
- (b) The aspect ratio (h/ℓ) used may be determined by rounding the calculated h/ℓ down to the nearest 0.05 increment value within the column, or by linear interpolation.
- (c) Regardless of discontinuity height or aspect ratio, discontinuity length shall not exceed $4t$.

NOTE: (1) For intermediate thicknesses, t [weld thicknesses between 2.5 in. and 3.9 in. (64 mm and 100 mm)], linear interpolation is required to obtain h/t values.